

Il quanto e il cosmo



Rocky Kolb
Fermilab & Univ. of Chicago

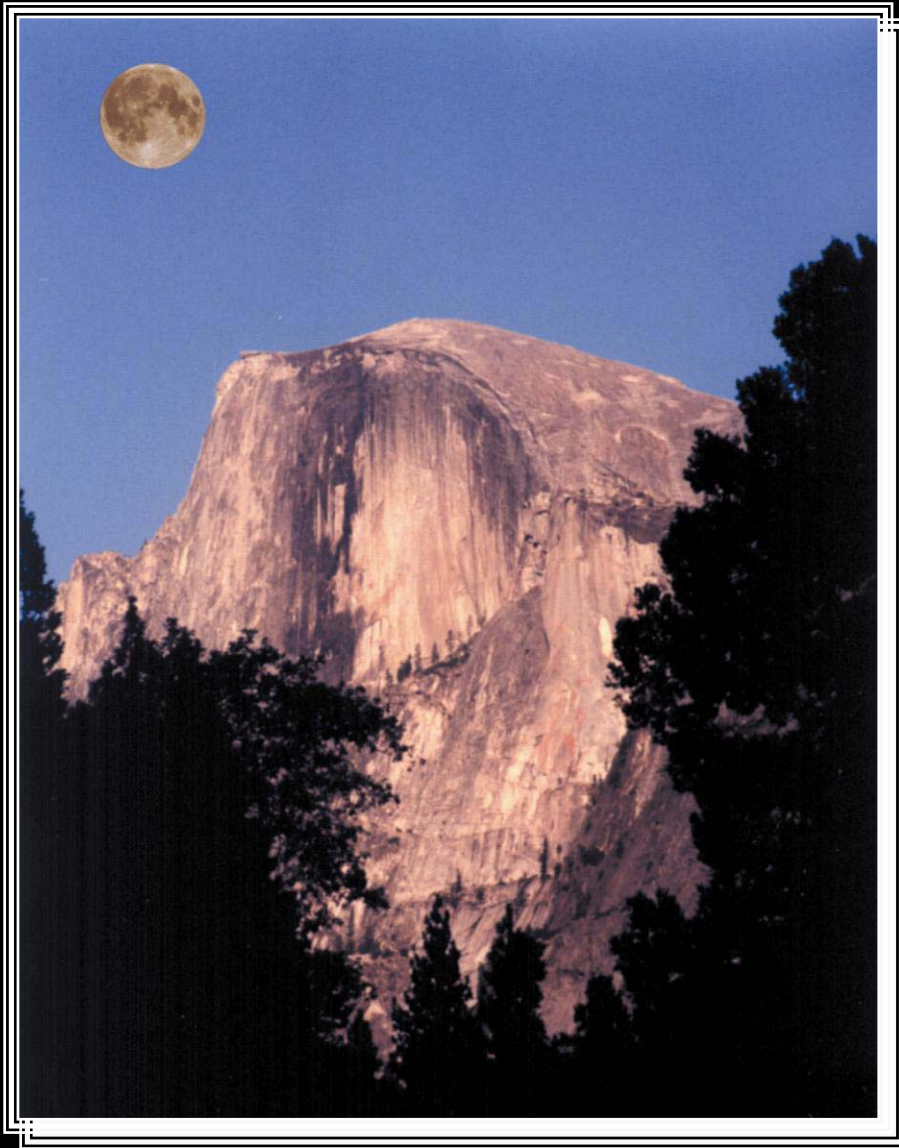
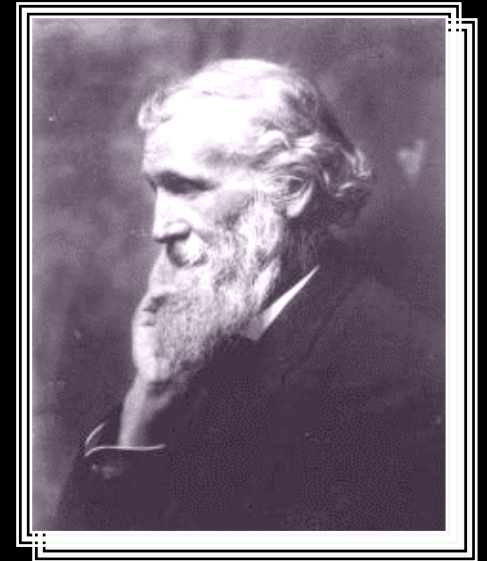
27 July 2001
la Sapienza

viale
dell'Astronomia

via
della Fisica

**When one tugs at a
single thing in
nature, he finds it
hitched to the rest
of the universe.**

— John Muir



A view of the universe circa 2000 C.E.



*art, literature, poetry, basketball,
opera, music, philosophy, ...ask*

“What is our place in the universe?”

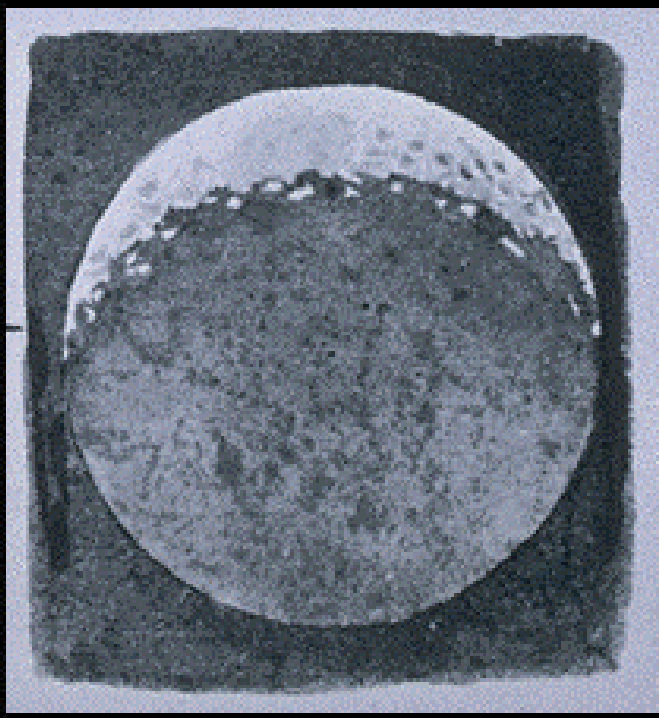
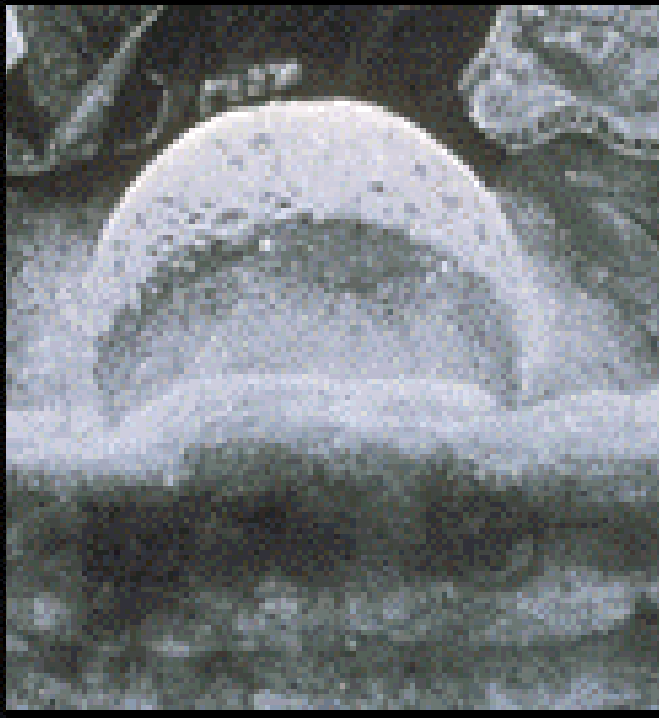
*science, in particular cosmology
and particle physics, asks*

“What is the universe?”

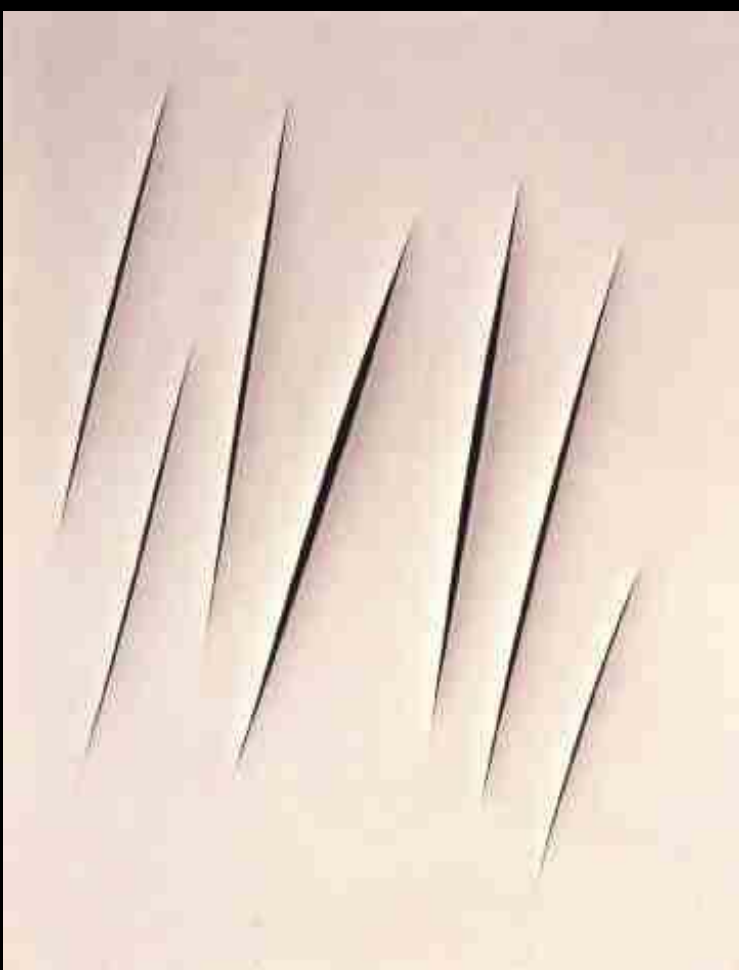
**Assumption of the Virgin (1610-1612) Lodovico Cigoli
Santa Maria Maggiore**



**Siderius Nuncius
Galileo 1608**



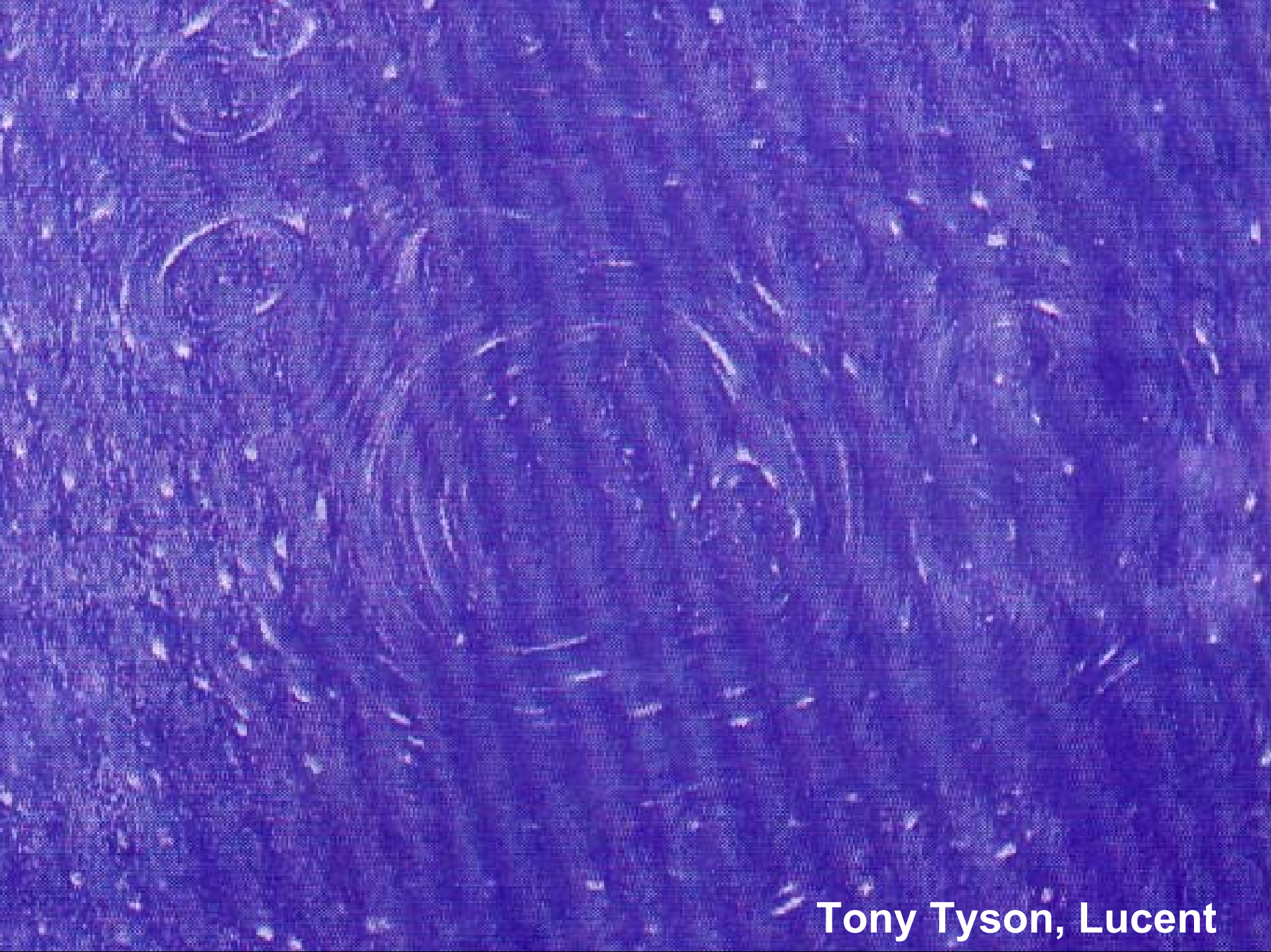
Lucio Fontana
Concetto Spaziale 1966



Jackson Pollack
Galaxy 1947



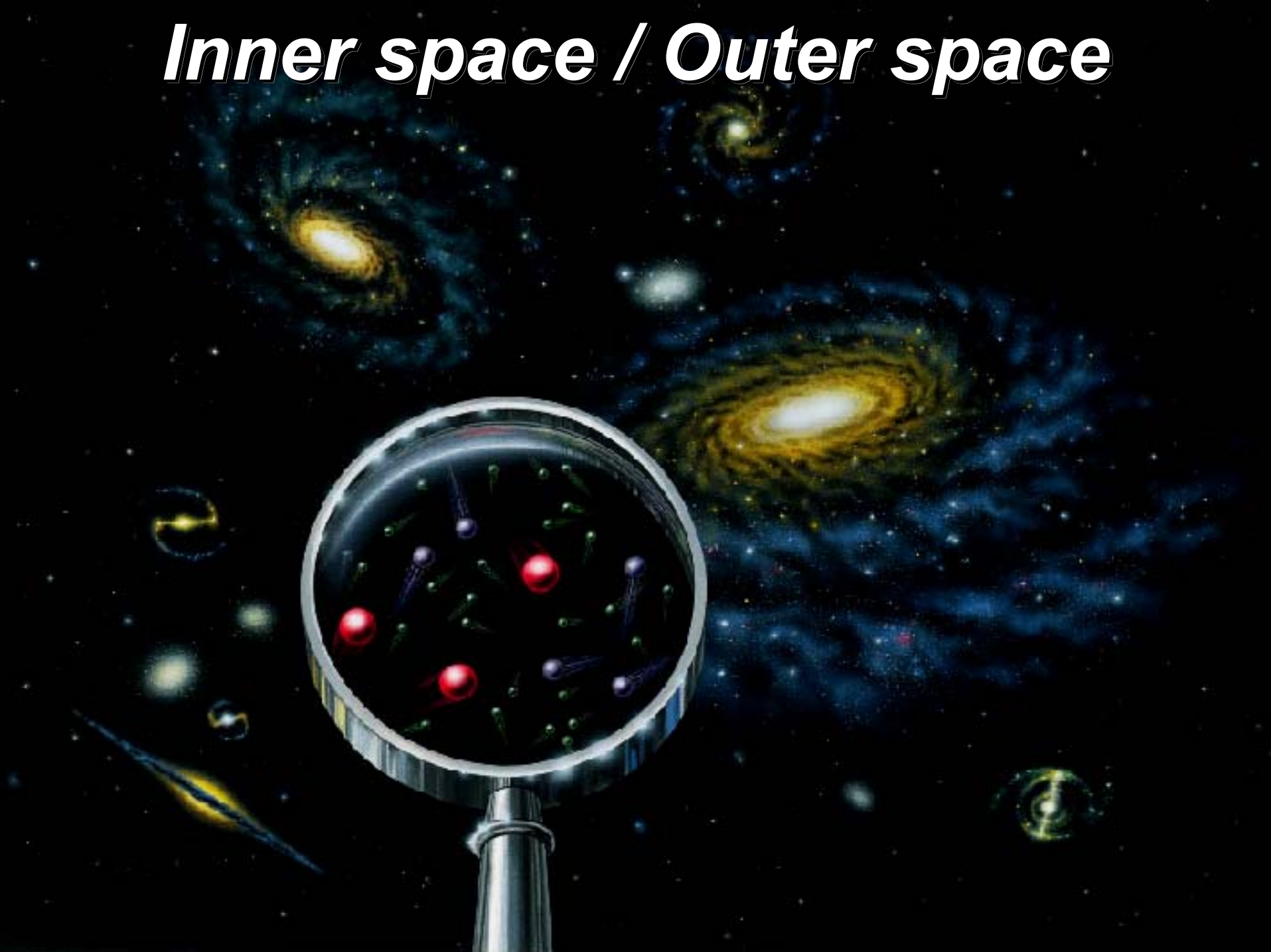
Gravitational Lens
Galaxy Cluster 0024+1654
Hubble Space Telescope • WFPC2



Tony Tyson, Lucent



Inner space / Outer space

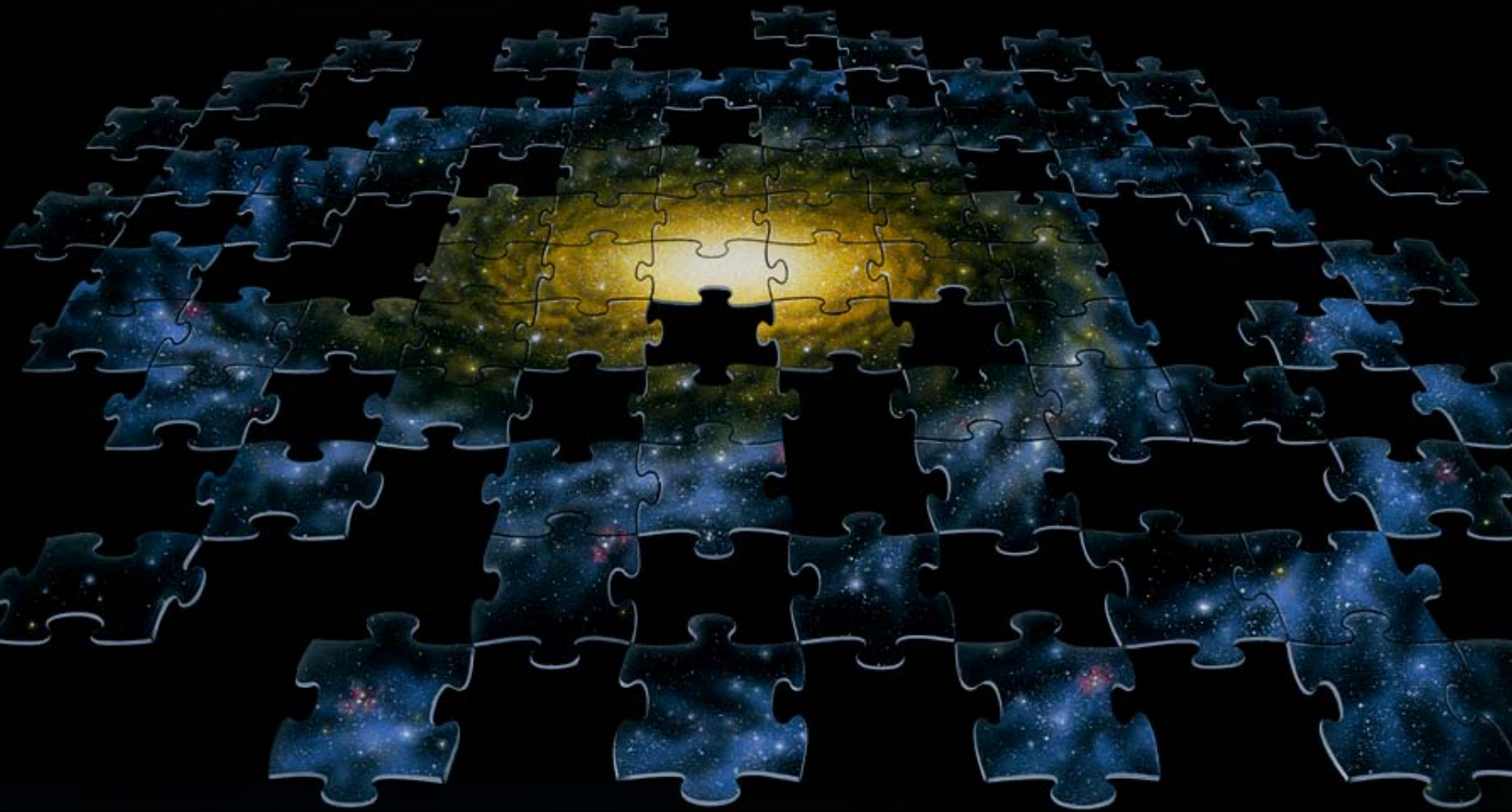


The composition of the universe?



Galaxies: Building blocks of the (visible) universe

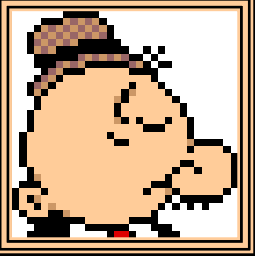
Missing pieces



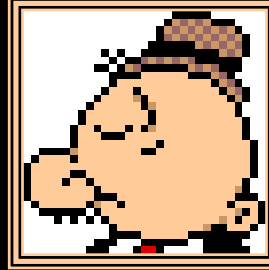
Dark Matter

Most of the universe is dark !

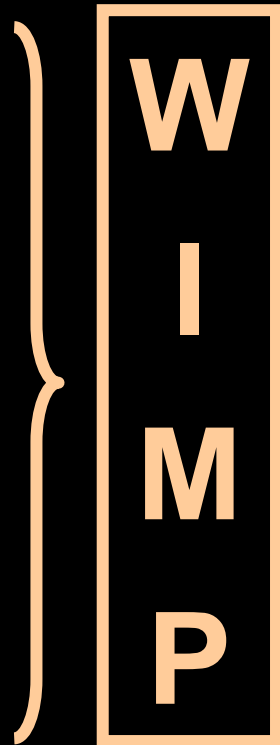
- Modify Newton's laws
- Rocky planets
- Mass disadvantaged stars
 - brown red white
- Black holes
- Fossil remnant of the big bang
- The weight of space



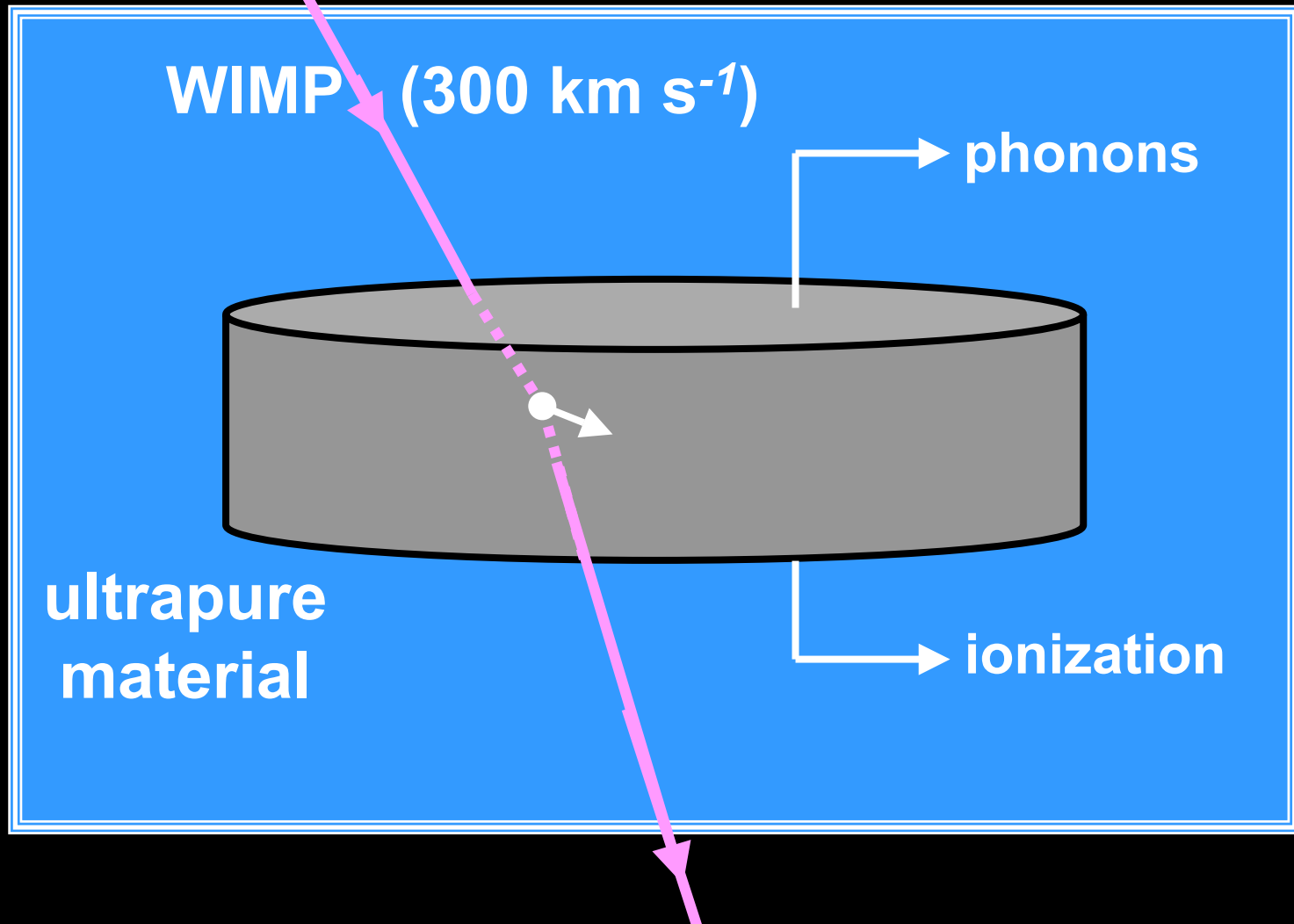
A wimpy idea



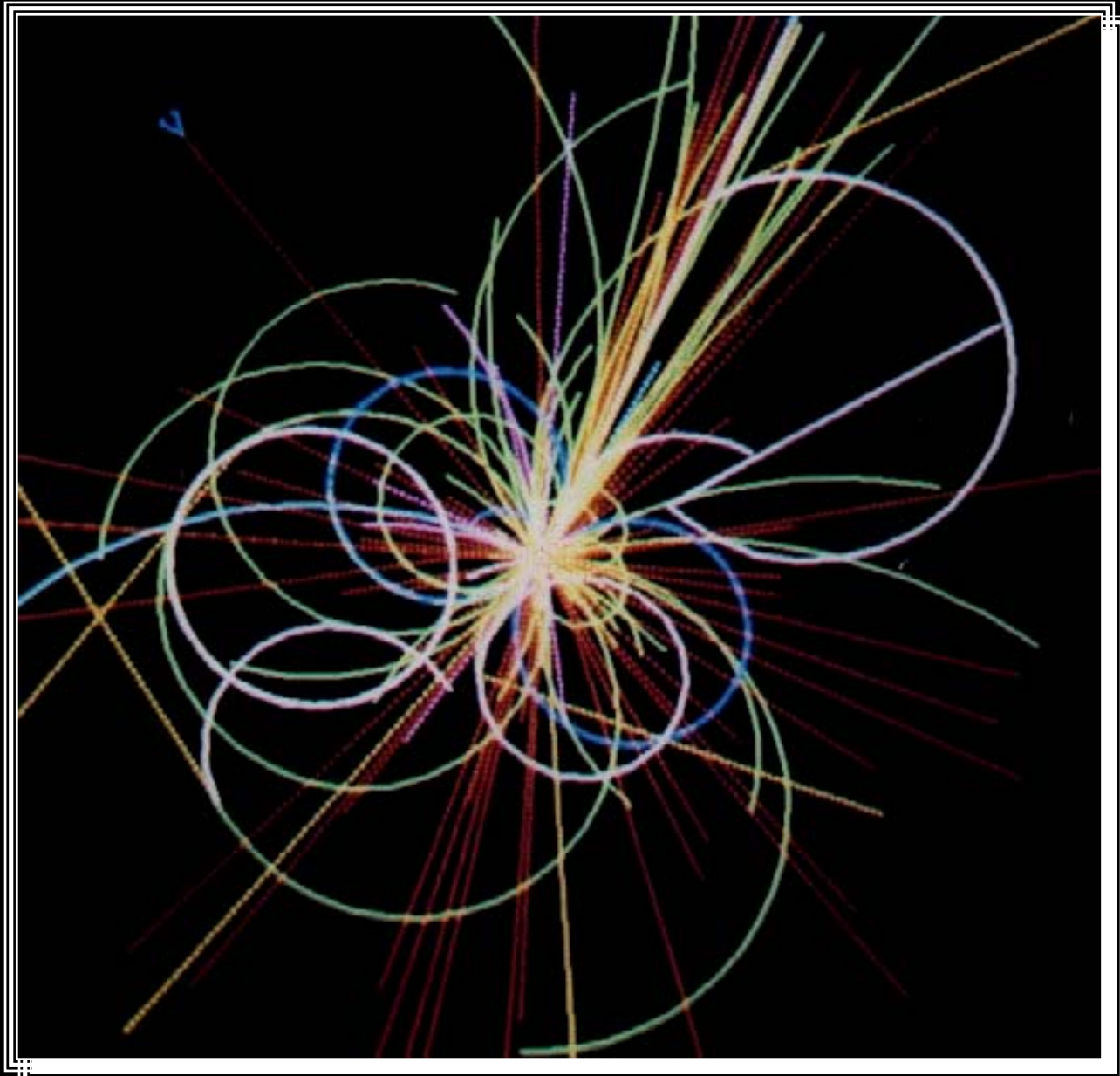
- Most of the universe is *invisible*
- Dominated by the rest mass of an elementary particle (quantum)
 - present in the primordial soup
 - massive
 - neutral
 - weakly interacting
 - slow
 - stable



Direct detection in Gran Sasso



Make wimps in the laboratory



Max ET = 51.1 GeV

MISS ET(3) = 78.8 GeV

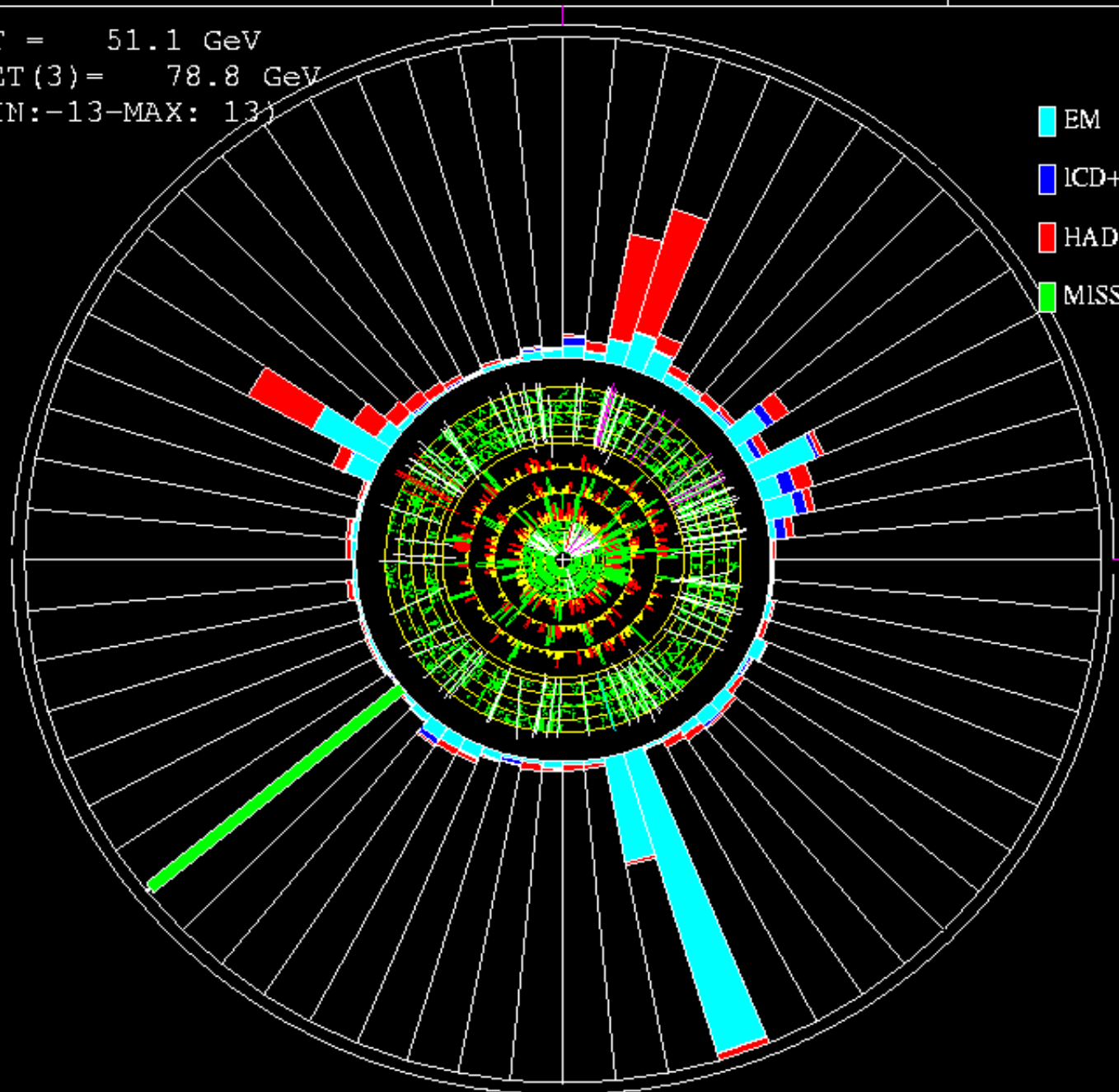
ETA(MIN:-13-MAX: 13)

EM






ICD+MG

HAD

MISS ET

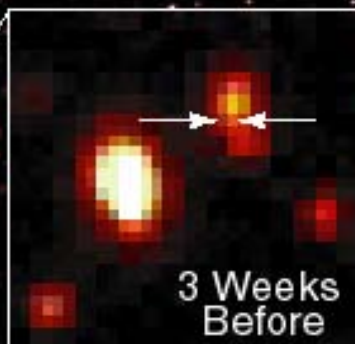
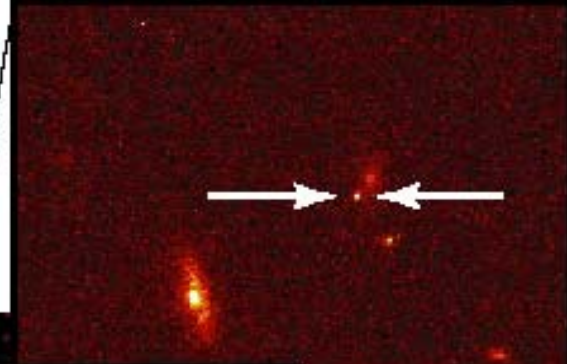


Desperately seeking **SUSY**

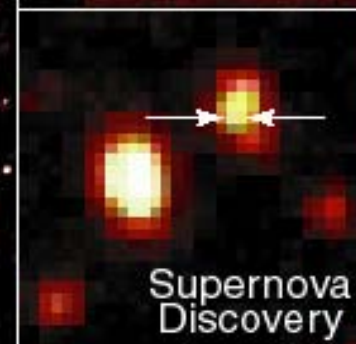
photons		photinos
selectrons		electrons
squarks		quarks
gravitons		gravitinos
wino		W

Lightest superpartner *stable!*

Supernova 1998ba
Supernova Cosmology Project
(Perlmutter, *et al.*, 1998)



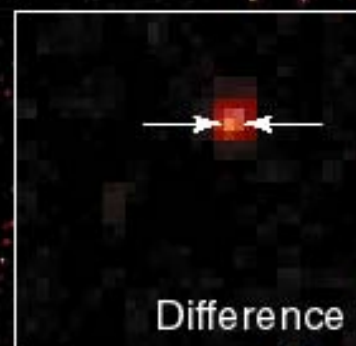
3 Weeks
Before



Supernova
Discovery

(as seen from
Hubble Space
Telescope)

(as seen from
telescopes
on Earth)



Difference

Cosmo-illogical constant

Mass density of space:

$$\rho \approx 10^{-30} \text{ g cm}^{-3}$$

The unbearable lightness of nothing!

The cosmic Chamber of Deputies

Radiation party: 0.02%

Visible matter party: 0.1%

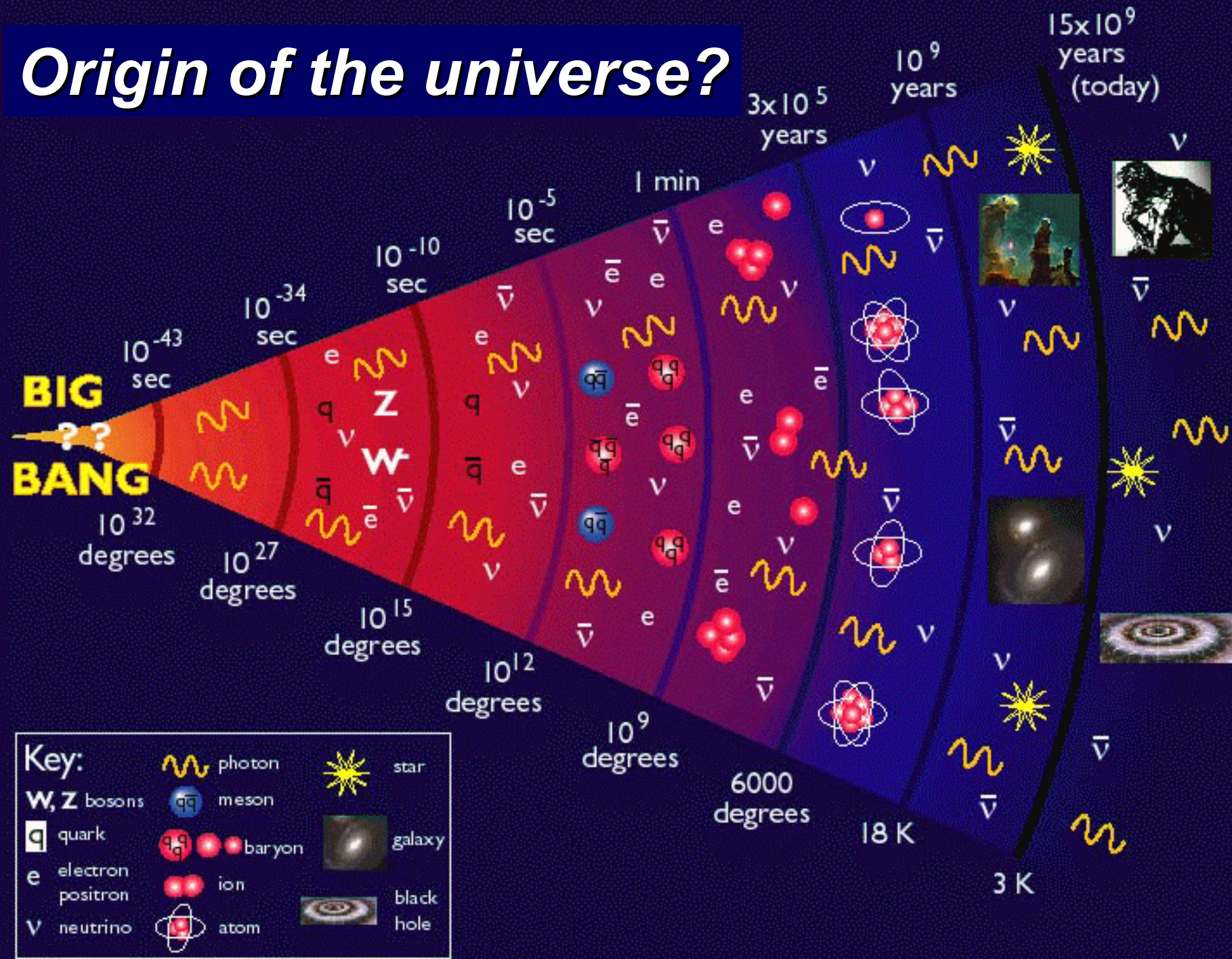
Neutrino party: 0.1%

Dark neutrons & protons party: 9.78%

Dark matter party: 30%

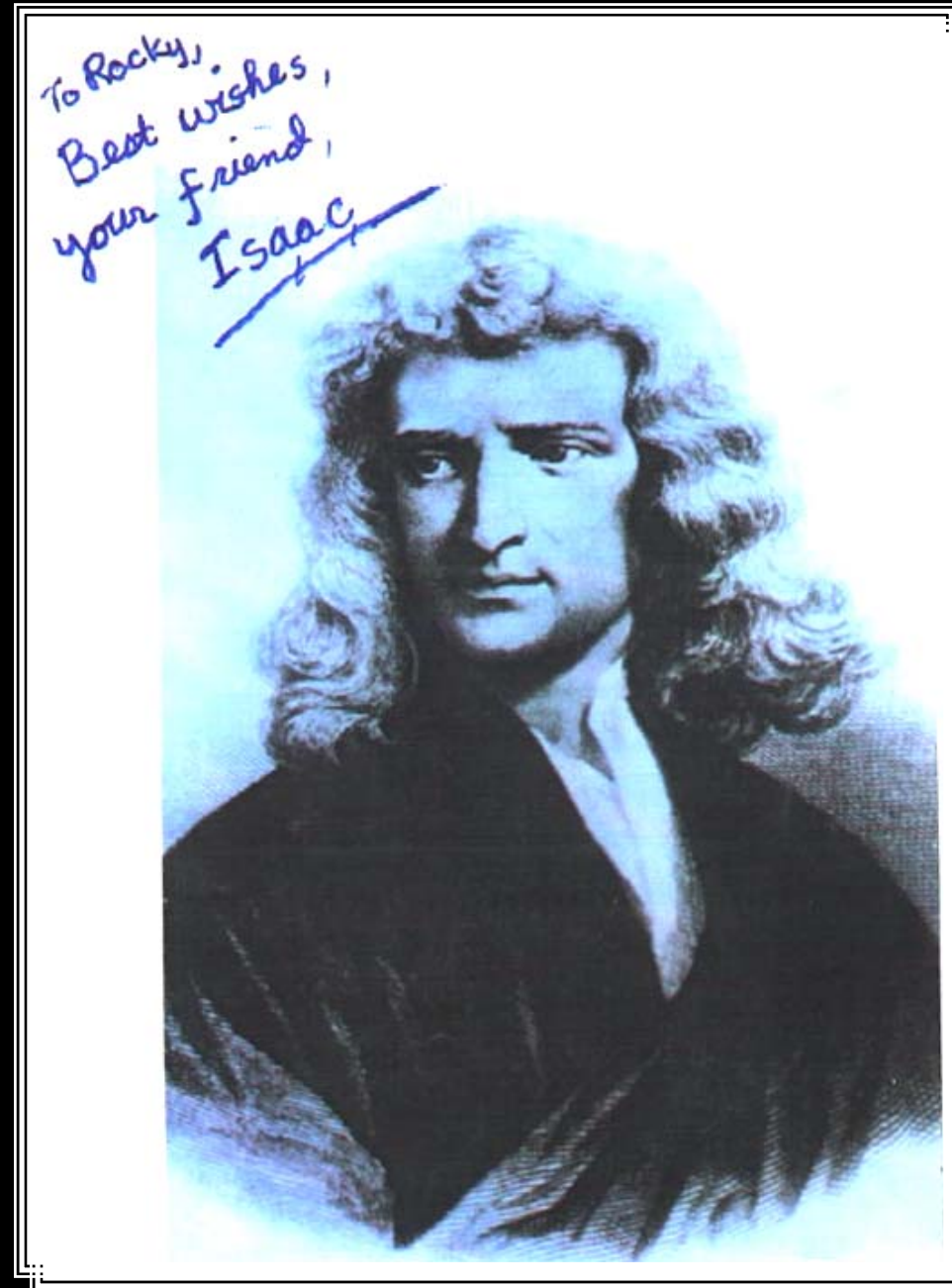
Dark energy party: 60%

Origin of the universe?



**Absolute space,
in its own nature,
without relation
to anything external,
remains always similar
and immovable.**

Isaac Newton
1686
Principia



**Space and time
are related.**

**Albert Einstein
1905**

**Space is dynamical
(curved, warped, bent,
etc.).**

**Albert Einstein
1915**



Space expands.

**Edwin Hubble
1929**



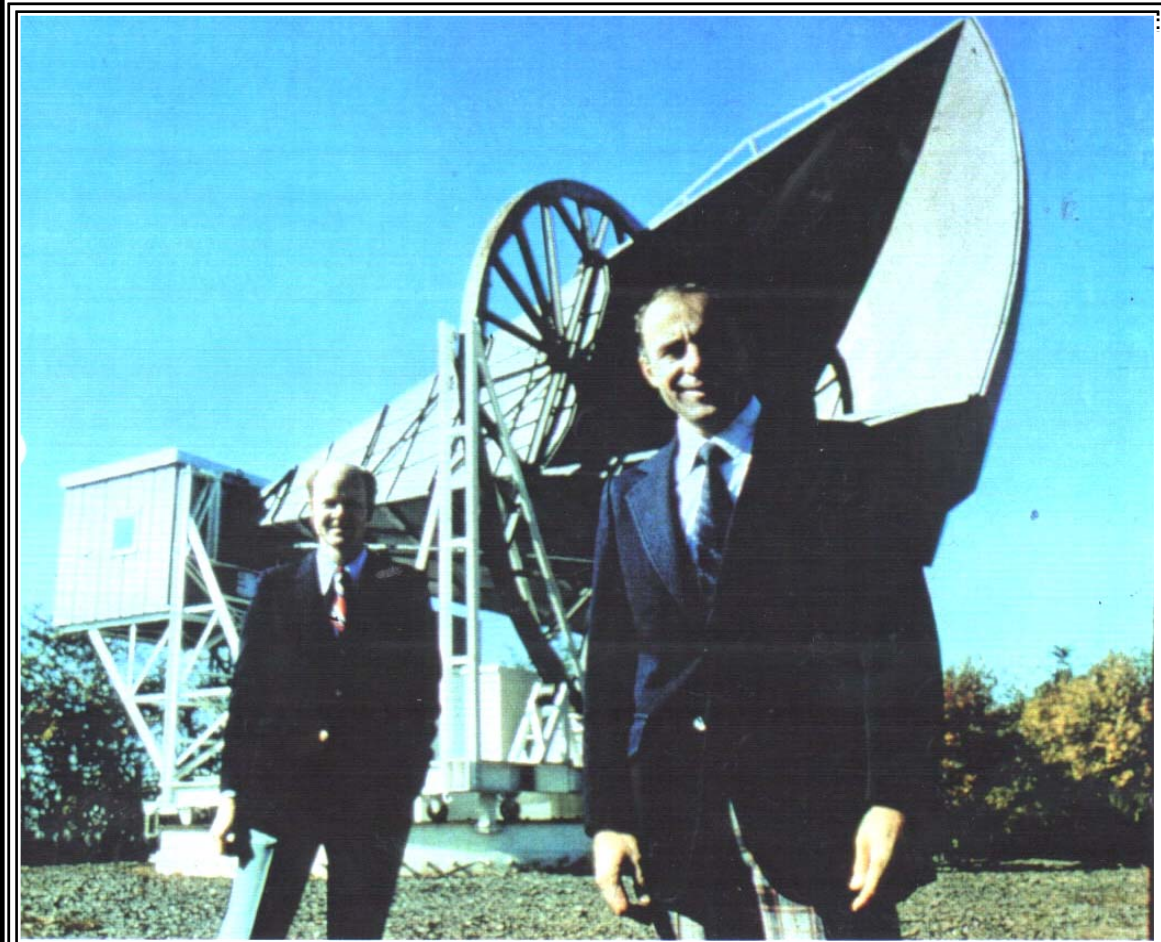
The University of Chicago



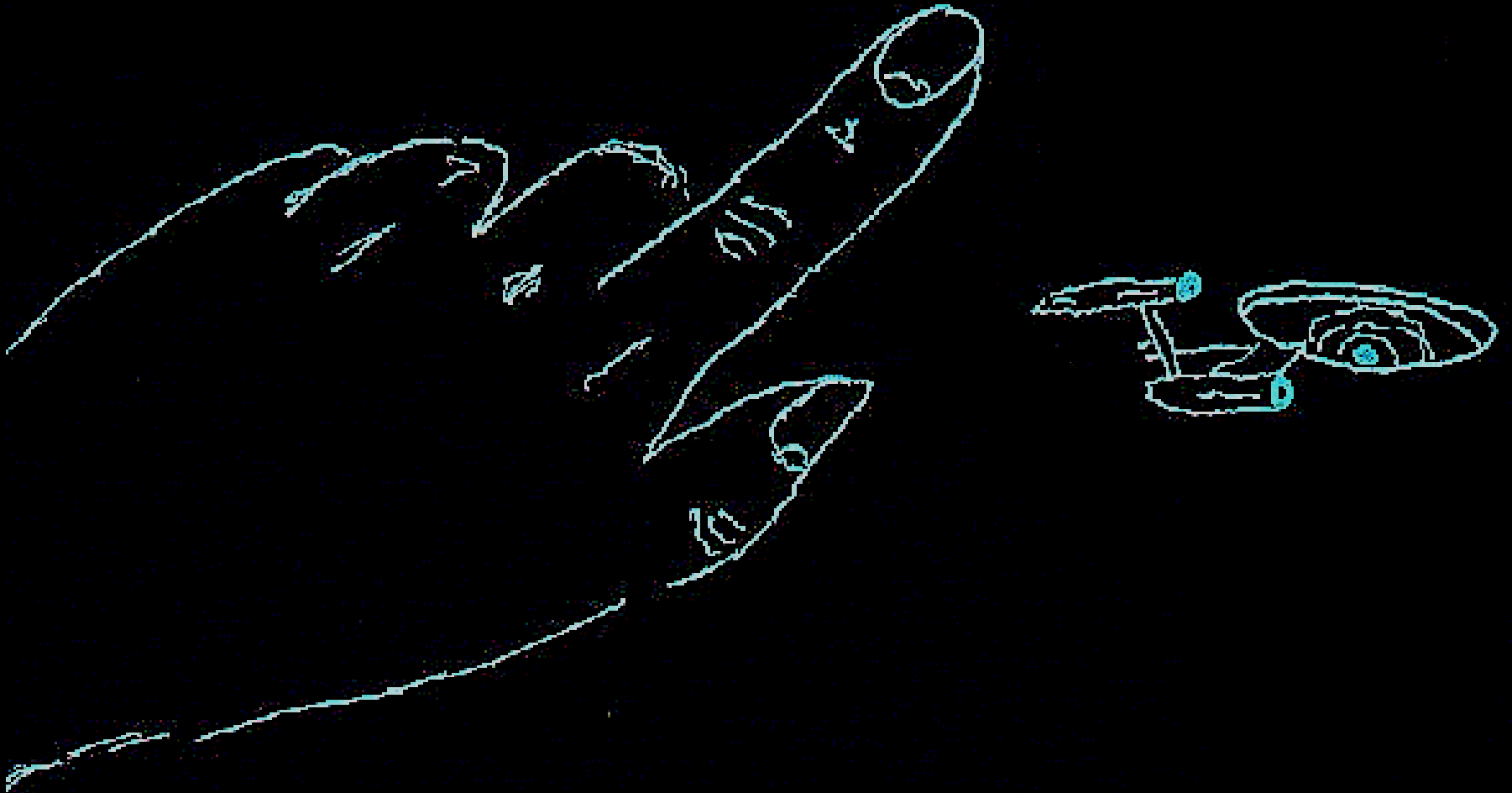
1909 National Champions

**The universe
is radiant.**

**Arno Penzias
Robert Wilson
1965**



Background radiation



$$T = 3K = - 270 \text{ C}$$

Possible future of the universe

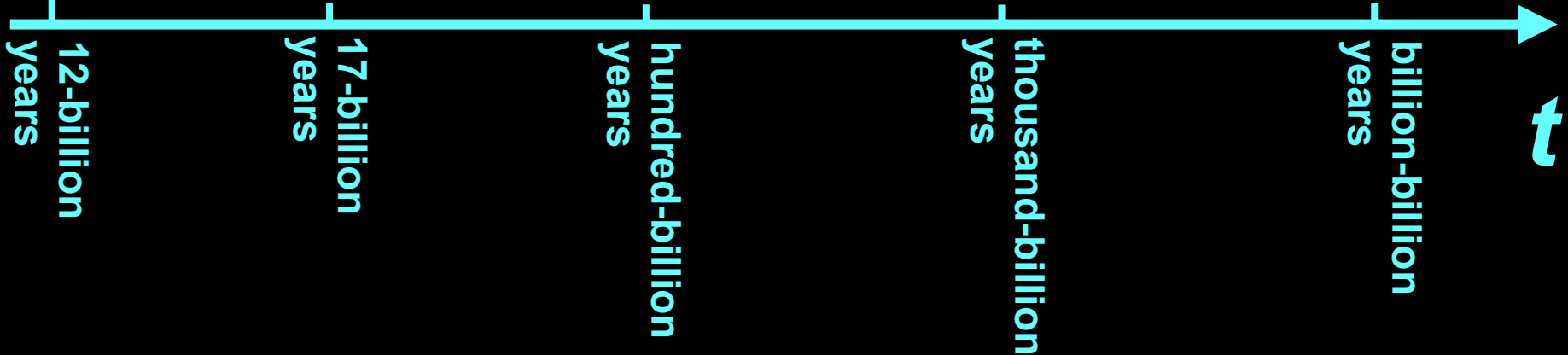
Sun burns
out

Hell Freezes Over

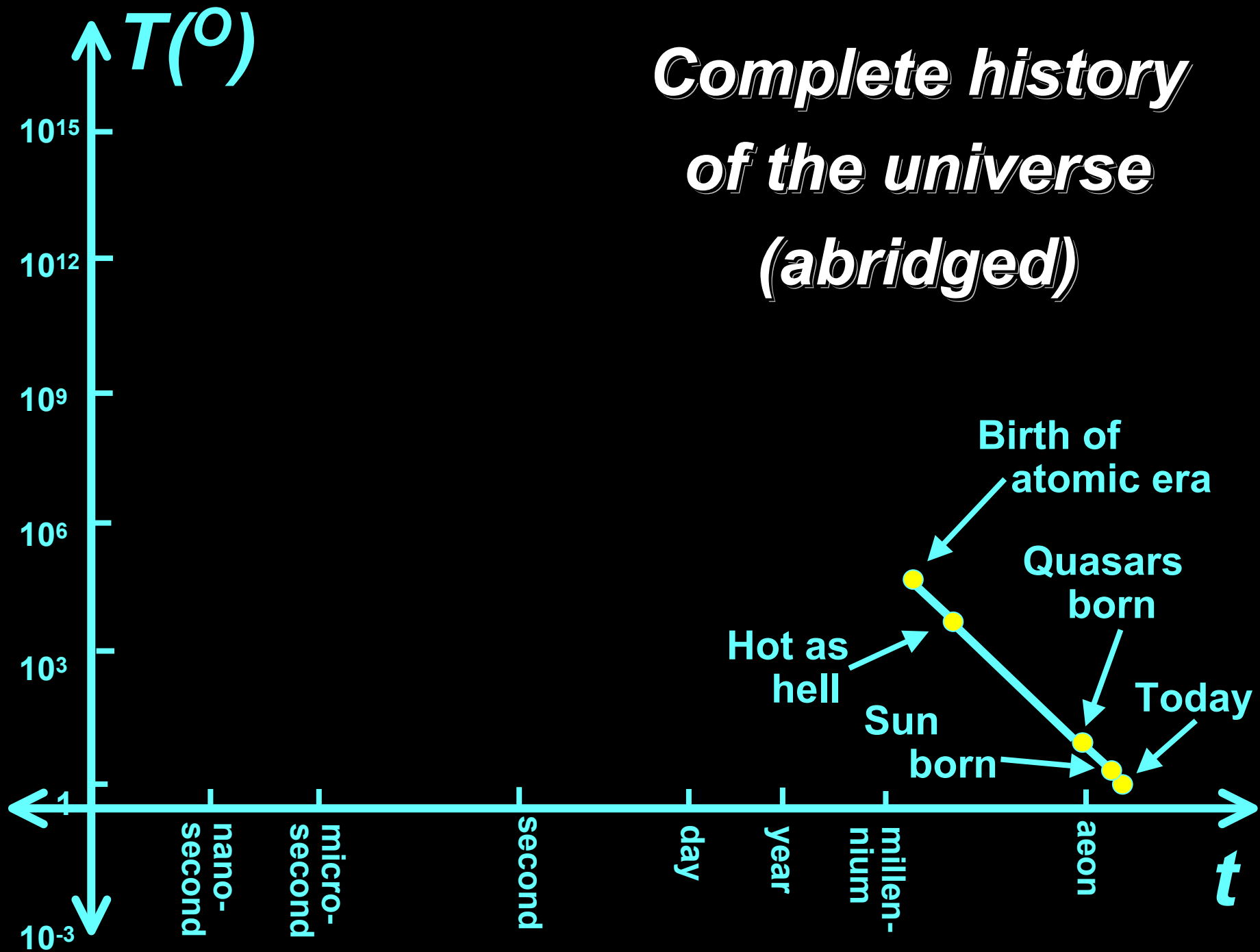
U.S. Wins World Cup

Universe Ends

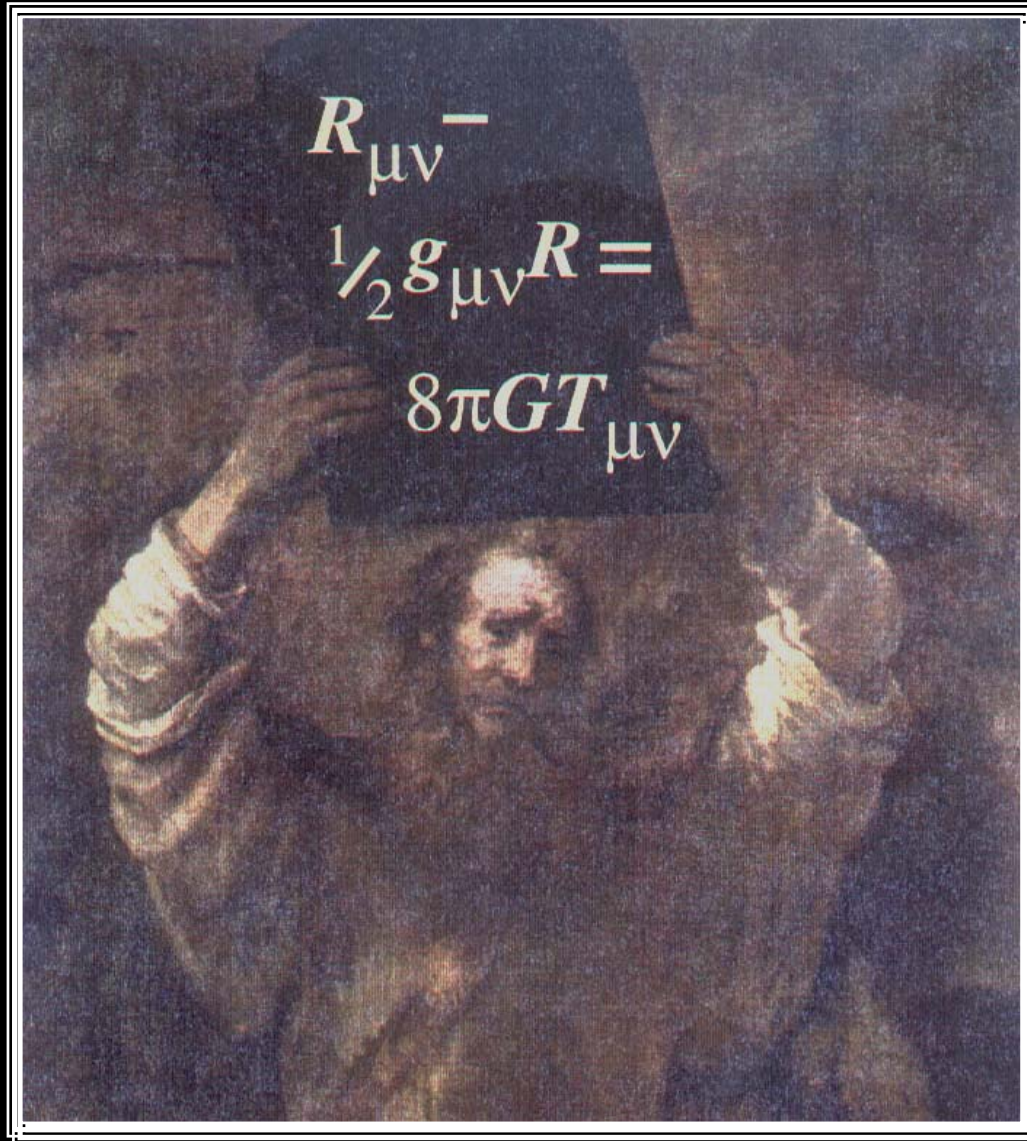
Today



Complete history of the universe (abridged)

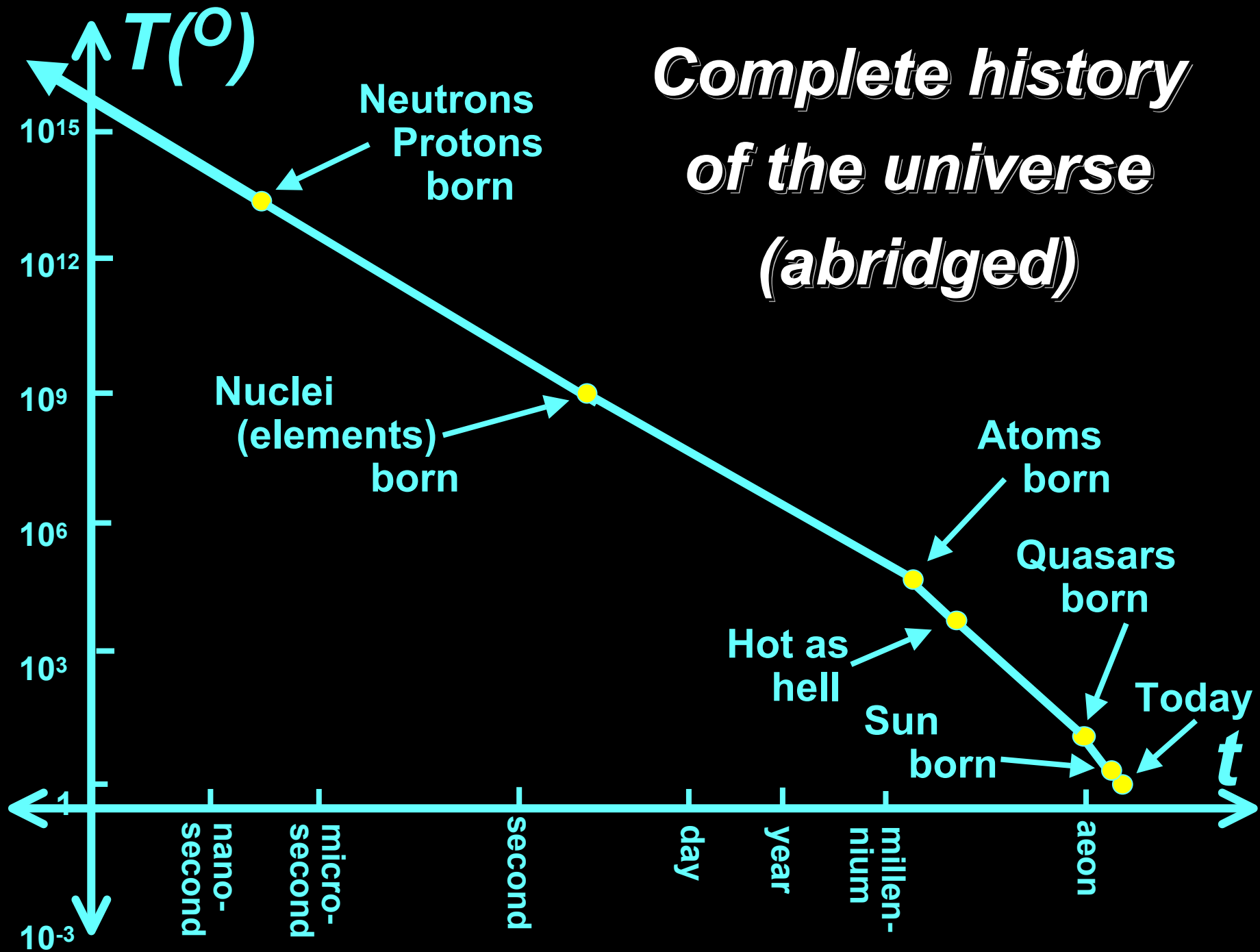


Modern laws of Genesis



(10 nonlinear partial differential equations)

Complete history of the universe (abridged)



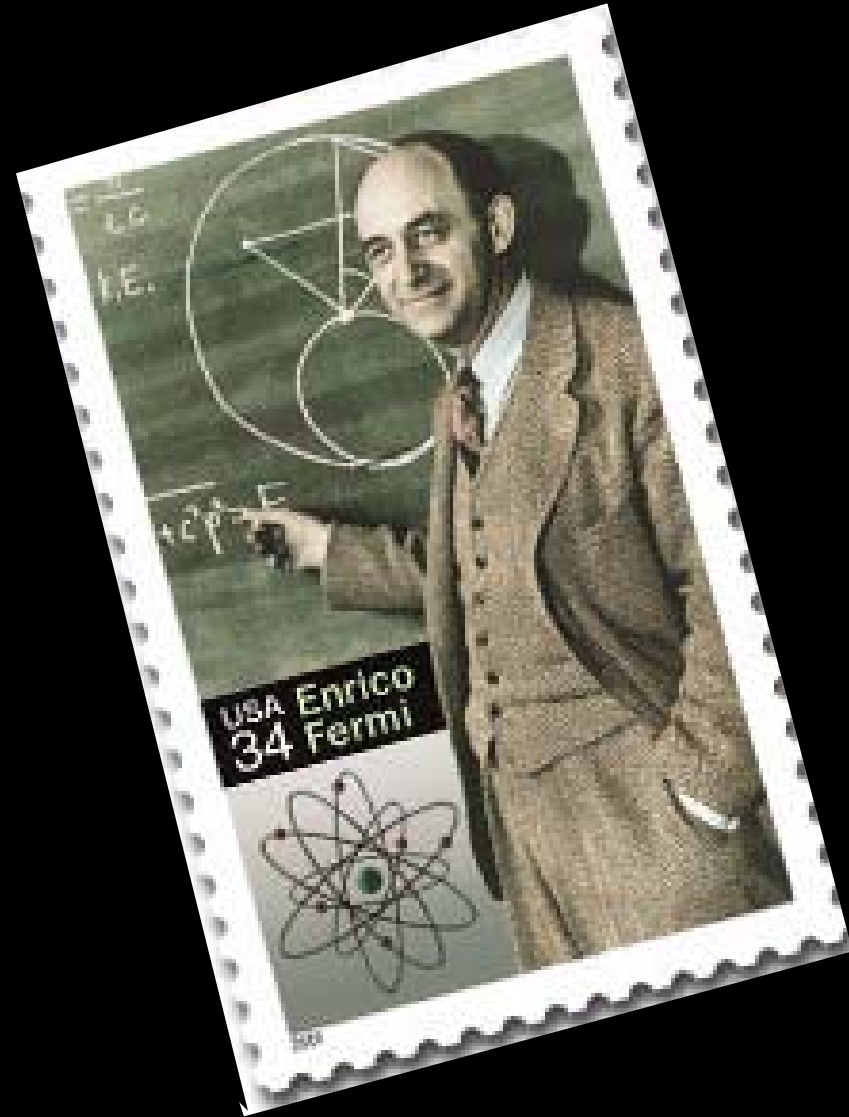
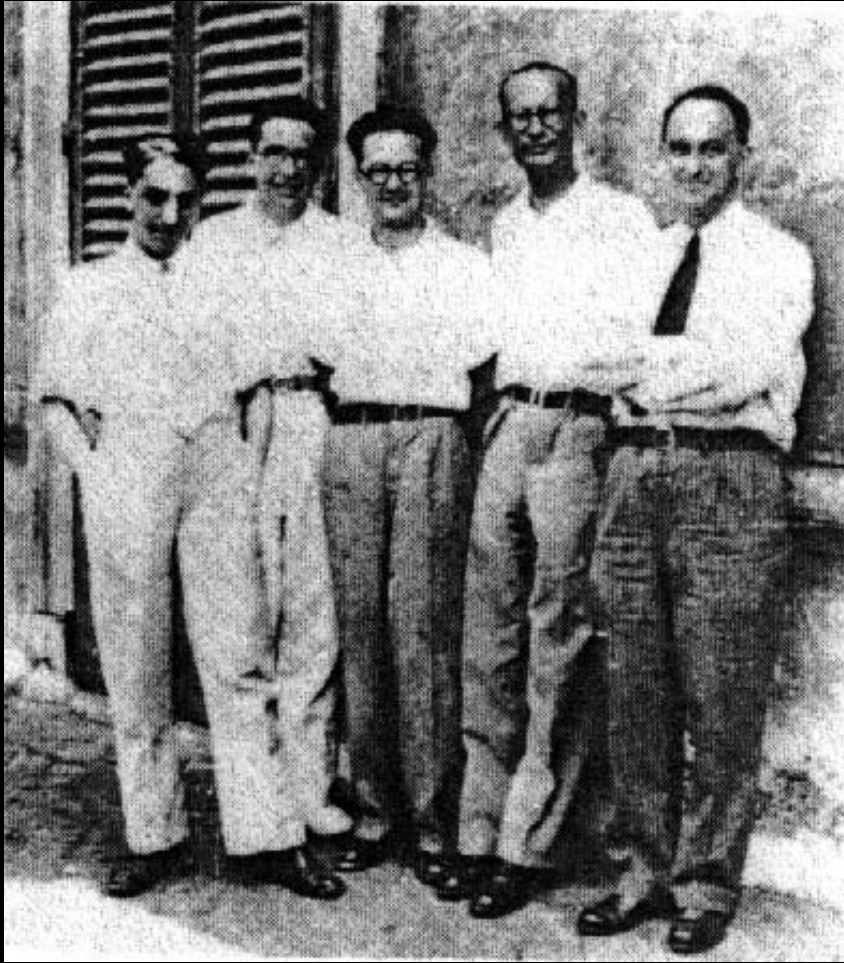
Fermilab – Batavia, USA



Particle Accelerator = Telescope = Time Machine

Enrico Fermi 1901 (Roma) – 1954 (Chicago)

Summer 1934, Roma



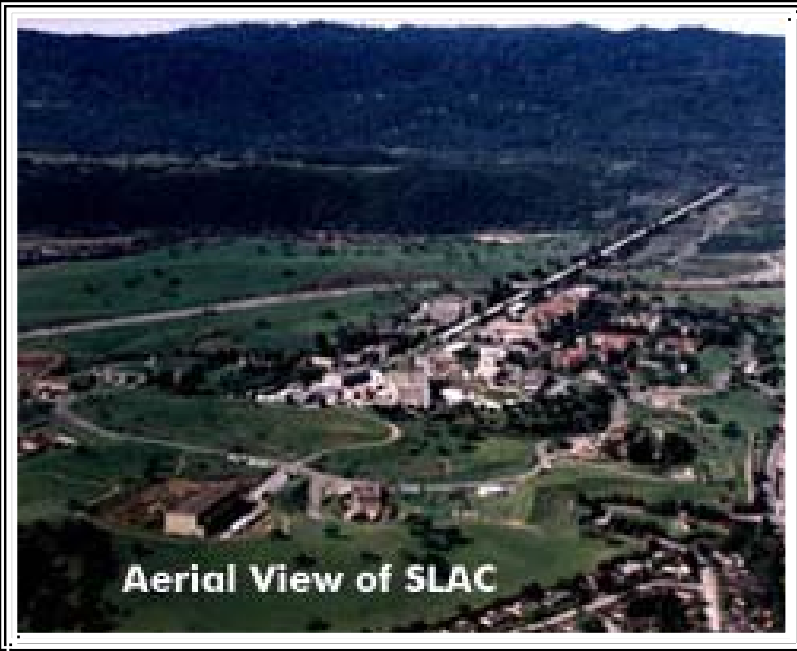
D'Agostino, Segre, Amaldi, Rasetti, Fermi

CERN – Geneva, Switzerland

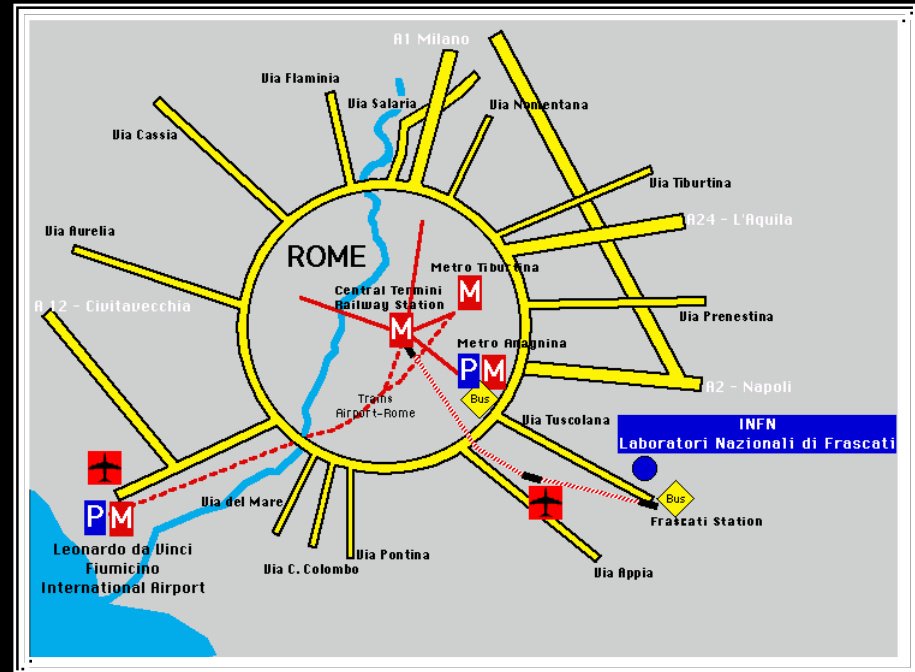


Particle Accelerator = Telescope = Time Machine

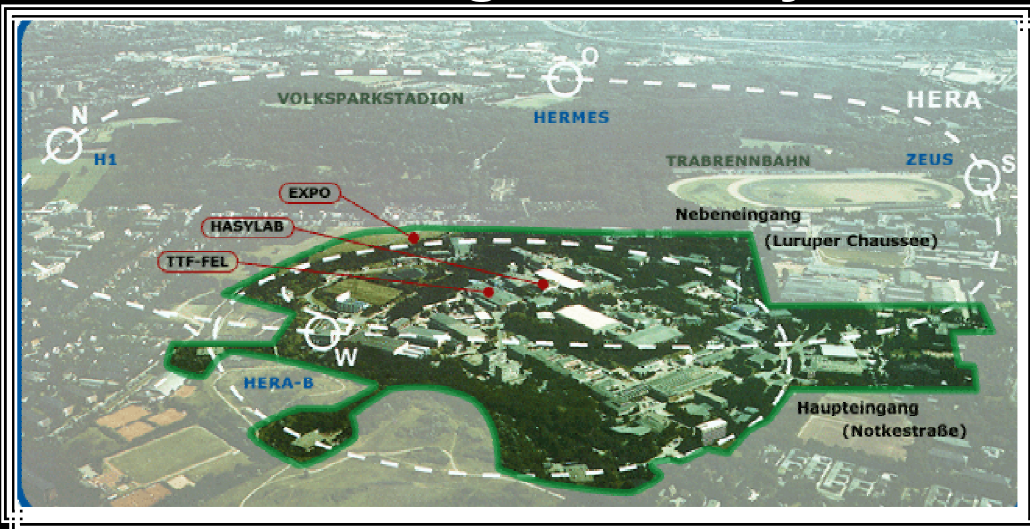
Stanford, USA



Frascati, Italia



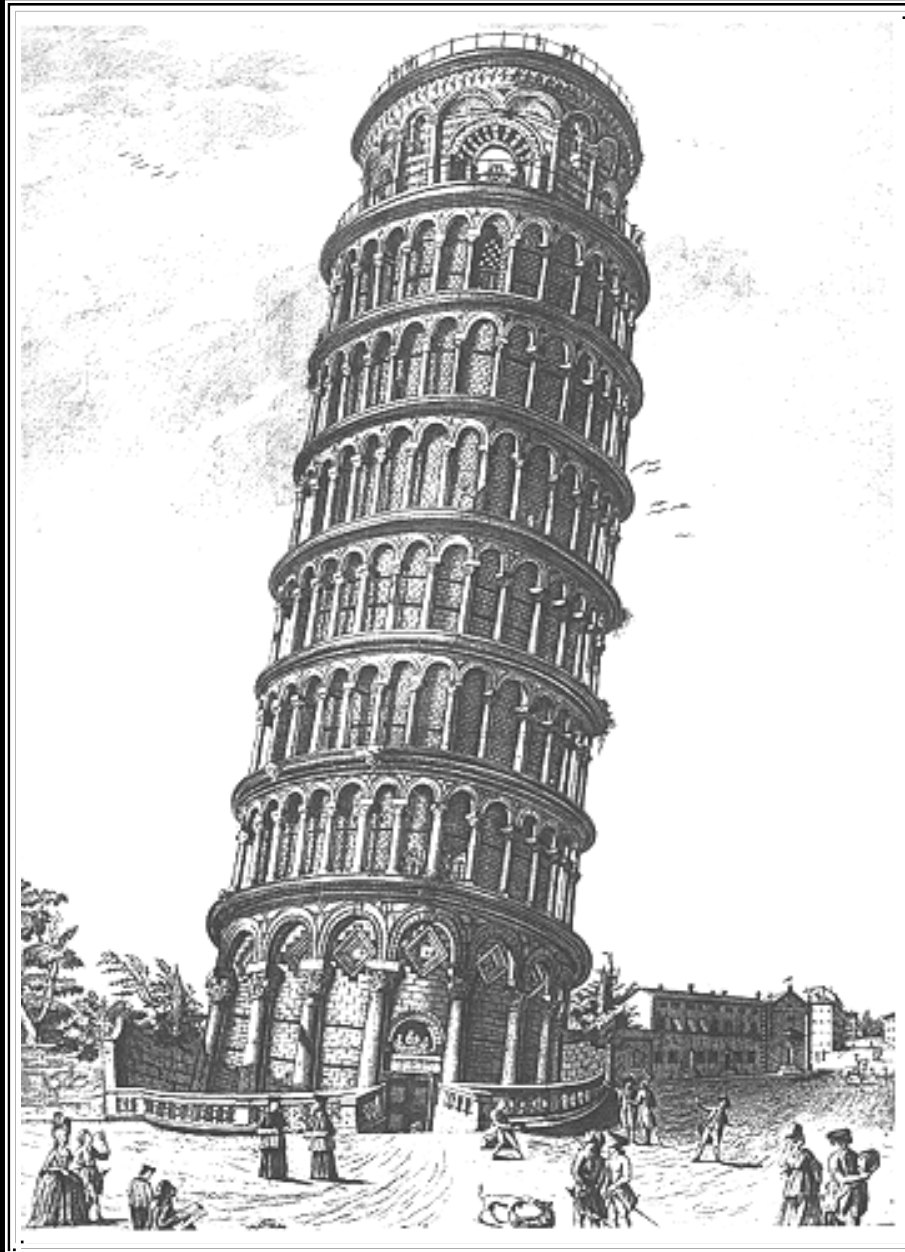
Hamburg, Germany



Tsukuba, Japan



Pisan Accelerator Laboratory





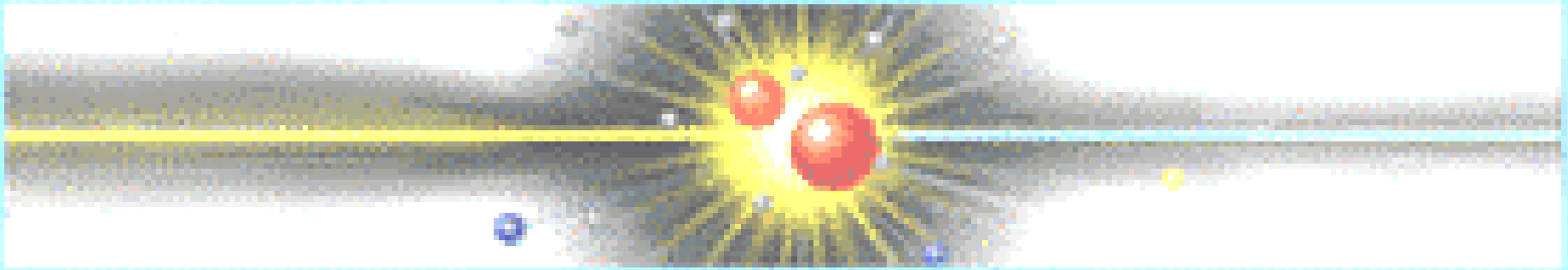
Fermilab's



Primordial

SOUP

Primordial soup



3×10^{15} degrees

3,000,000,000,000,000°

4×10^{-12} seconds

0.000 000 000 004 seconds

Primordial soup



Caution !!!

CONDENSED

50 Earth masses in matter

50 Earth masses in antimatter

+ extra mountain of matter

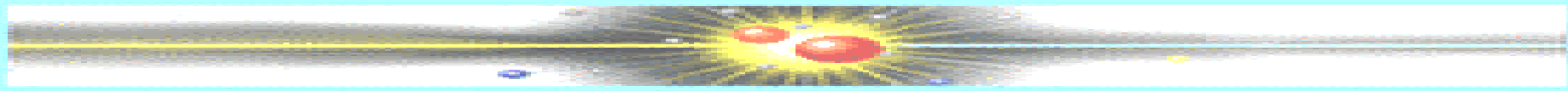
HOT

64 billion years of energy output of sun

CONTENTS

elementary particles and antiparticles

Primordial soup



KNOWN INGREDIENTS:

56% QUARKS

16% GLUONS (STRONG FORCE)

9% ELECTRON-LIKE PARTICLES

9% W's AND Z's (WEAK FORCE)

5% NEUTRINOS

2% PHOTONS (ELECTROMAGNETIC FORCE)

2% GRAVITONS (GRAVITATIONAL FORCE)

1% HIGGS BOSONS (???)

SECRET INGREDIENT:

DARK MATTER

Quarks come in six flavors:

**Up
Down**

**Charmed
Strange**

**Top
Bottom**

or

**Spumone
Cioccolata**

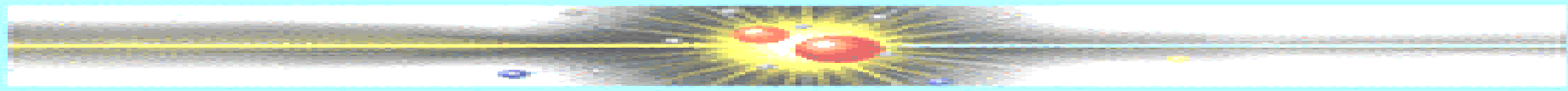
**Mandorla
Panna**

**Ananas
Limone**

and

Each flavor comes in three colors

Primordial soup



KNOWN INGREDIENTS:

56% QUARKS

16% GLUONS (STRONG FORCE)

9% ELECTRON-LIKE PARTICLES

9% W's AND Z's (WEAK FORCE)

5% NEUTRINOS

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1% HIGGS BOSONS (???)

SECRET INGREDIENT:

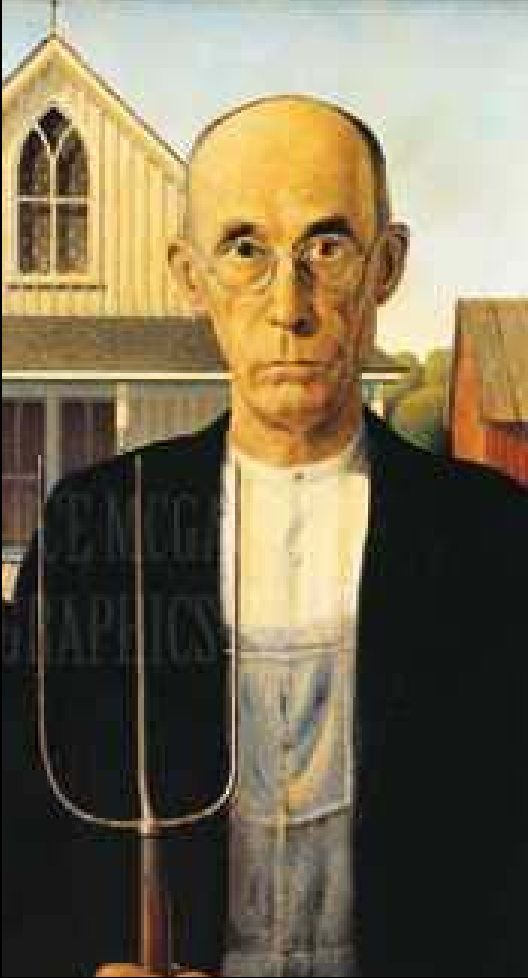
DARK MATTER

Will Higgs be found in

USA (Fermilab)?

or

Europe (CERN)?



Mike Witherell
Director



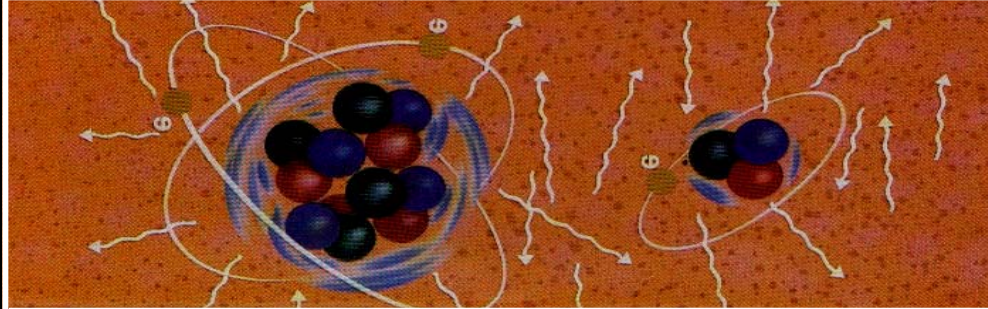
Luciano Maiani
Director General



Prof. Peter Higgs

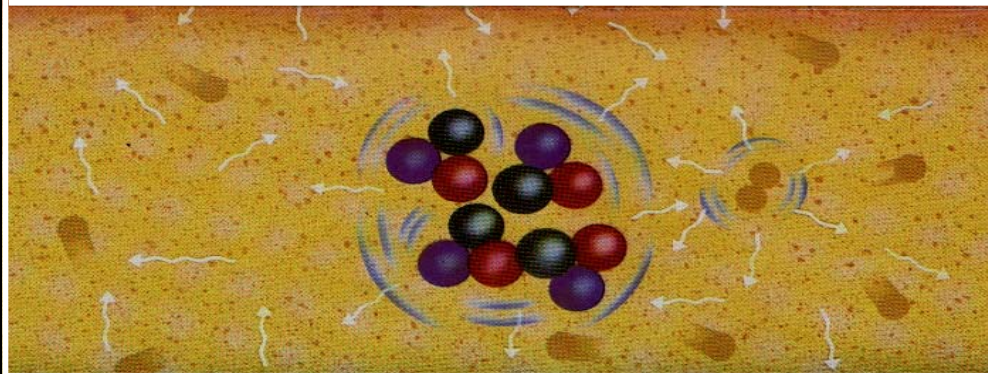
Unidentified

**300,000
years**



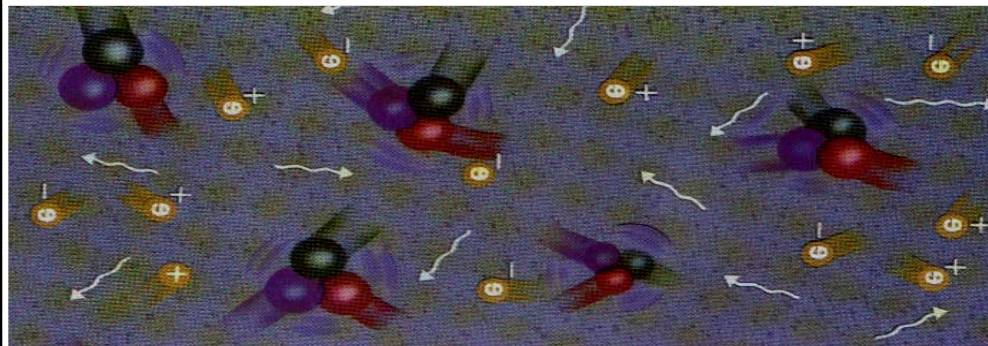
**atoms
form**

**3
minutes**



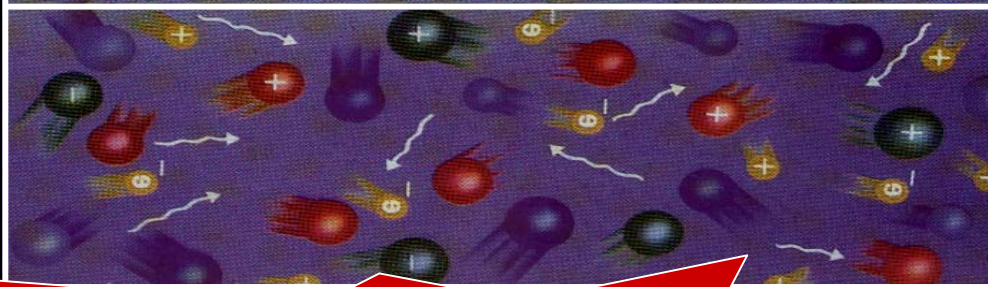
**nuclei
form**

**1-micro
second**



**neutrons
protons
form**

**4-pico
seconds**



**primordial
soup**

BANG!

Periodic table - chemist

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Uun	Uuu	Uub						
			La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
			Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

Periodic table - cosmologist

H

He

Metals

The Universe Today:

73% Hydrogen (10^{-5} deuterium)
26% Helium (10^{-5} ^3HE)
1% Metals

The Universe 3 minutes AB:

76% Hydrogen (10^{-5} deuterium)
24% Helium (10^{-5} ^3HE)
 $10^{-8}\%$ Lithium

Primordial antipasto?

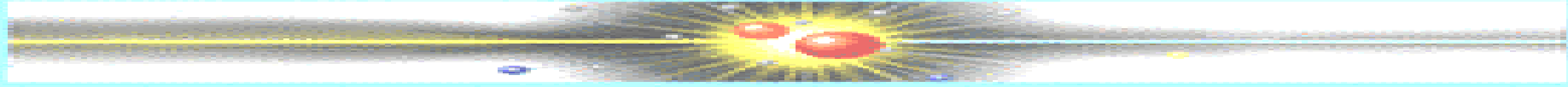
At time zero:

- infinite temperature
- infinite pressure
- infinite density
- infinite curvature

At time zero:

- spacetime singularity
- physical law breaks down
- no predictions possible
- *here be dragons!*

Before primordial soup



NOTHING!!! (vacuum)

MUCH ADO ABOUT NOTHING:

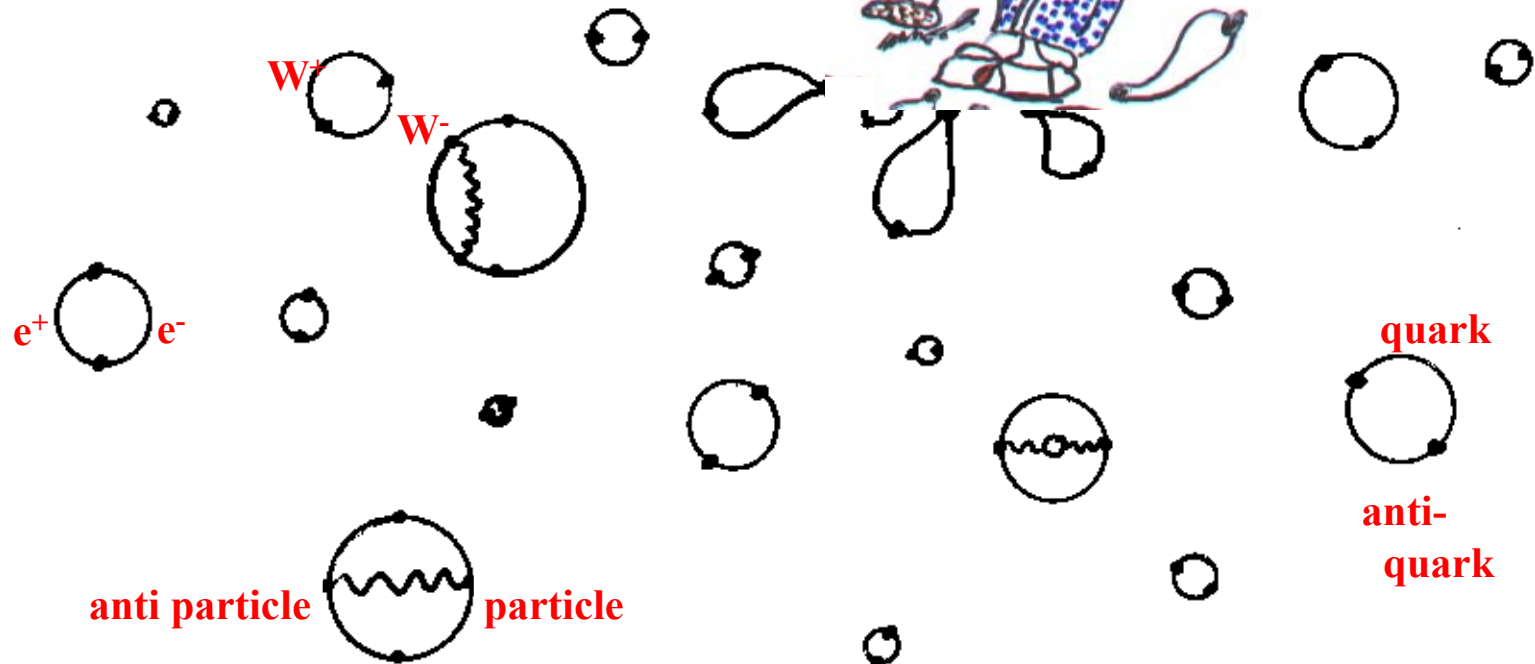
NOTHING is something

NOTHING has energy

NOTHING can change

The Vacuum

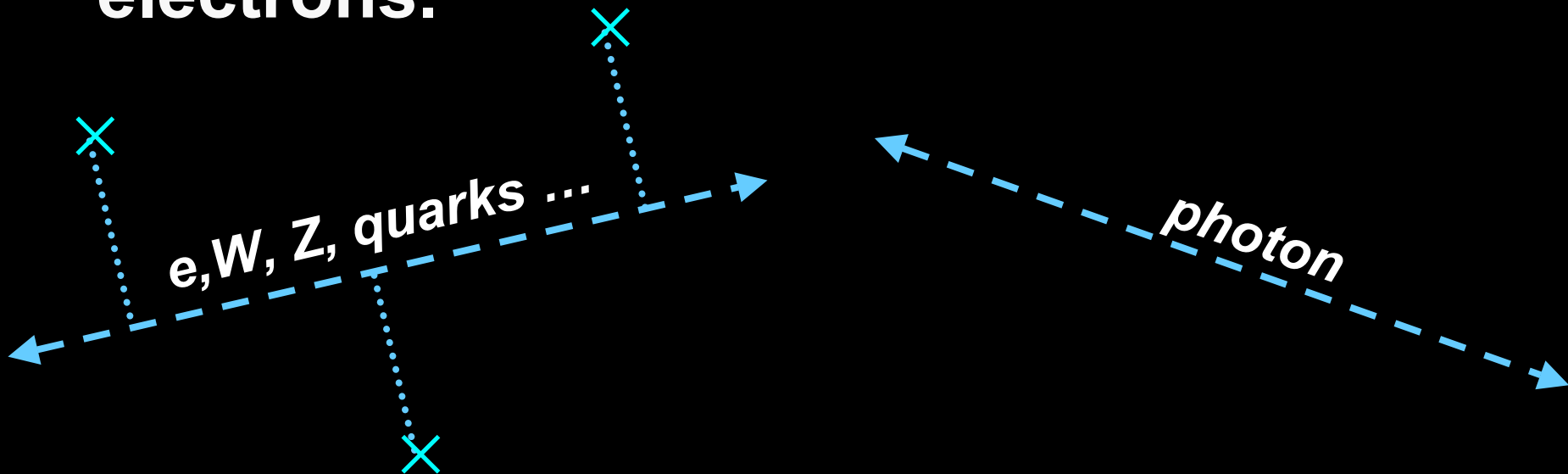
of

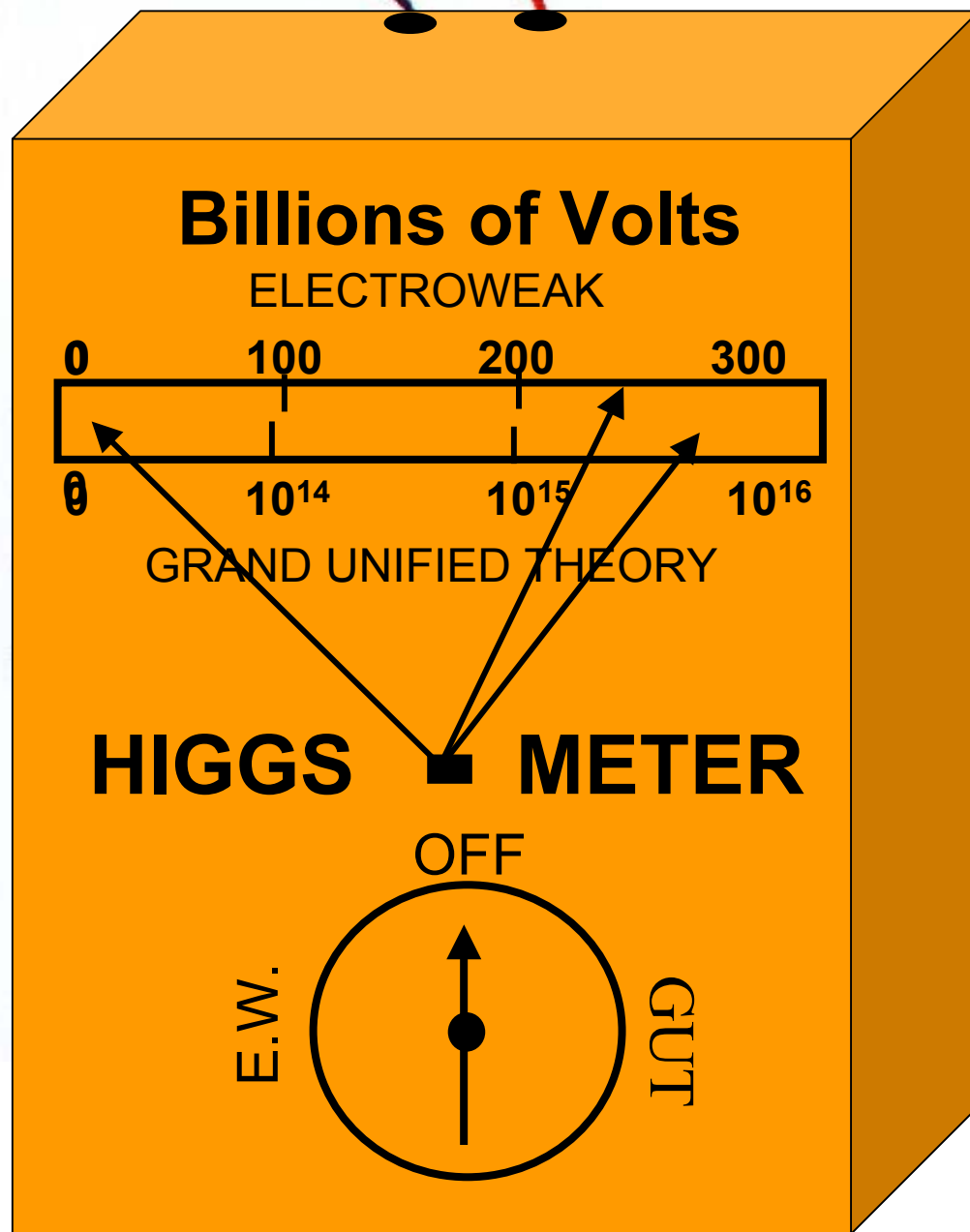


Quantum Uncertainty

Nothing has energy: the Higgs potential

- The vacuum has a “Higgs potential”
- Interaction with the Higgs field potential gives mass to particles like quarks and electrons.





Every cubic inch of space is a

MIRACLE!

- Walt Whitman

- background radiation
- virtual particles
- Higgs vacuum

Nothing can change

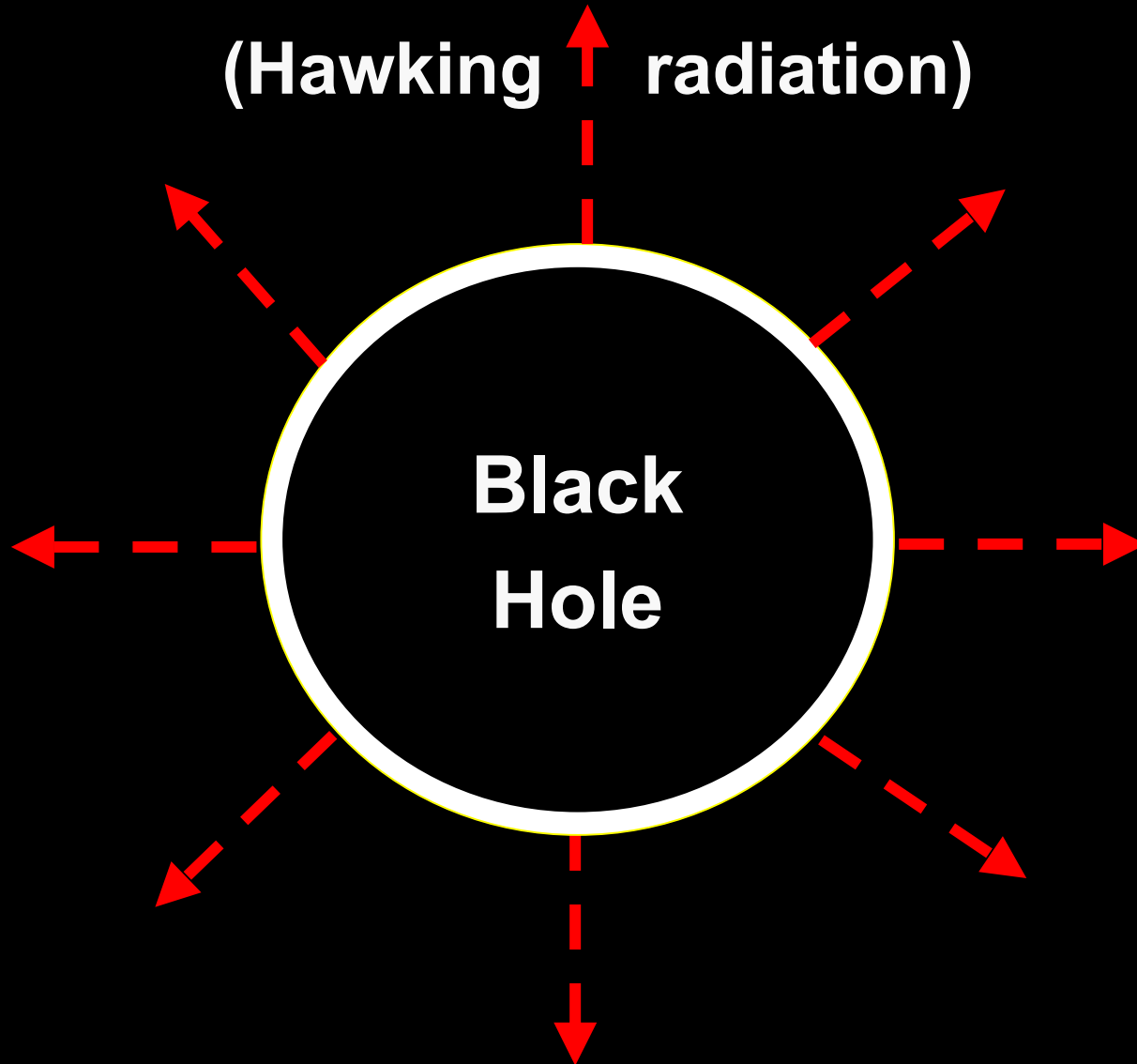
- Today the density of nothingness is less than 10^{-30} grams per cc
- Before primordial soup the density of nothingness may have been larger than 10^{+30} grams per cc
- The primordial soup came from vacuum discharge (inflation)

**“For every complex natural phenomenon
there is a simple, elegant, compelling,
wrong explanation.”**

- *Tommy Gold*

The quantum and the vacuum

Strong gravitational field \longrightarrow particle production
(Hawking \uparrow radiation)



An early particle cosmologist



In mid-1930s, Schrödinger turned to cosmo issues

1938-1939: Graz → Vatican → Belgium → Ireland

The Proper Vibrations of the Expanding Universe

Erwin Schrödinger

Physica 6, 899 (1939)

Introduction:

“... proper vibrations [particles and antiparticles] cannot be rigorously separated in the expanding universe. ... this is a phenomenon of outstanding importance. With particles it would mean production or annihilation of matter, merely by expansion,... Alarmed by these prospects, I have examined the matter in more detail.”

Conclusion:

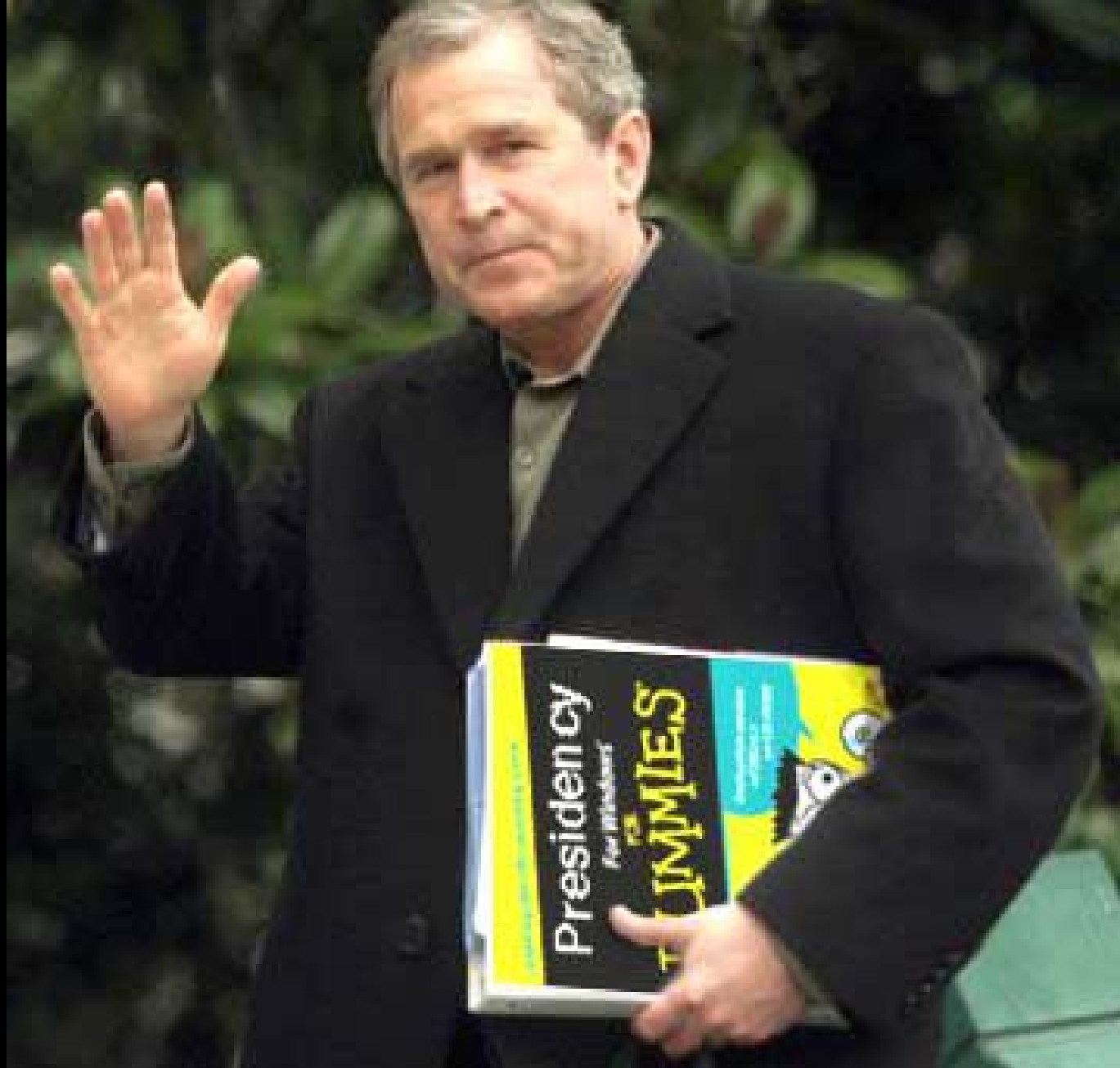
“There will be a mutual adulteration of positive and negative frequency terms in the course of time, giving rise to ... the ‘alarming phenomenon’...”

An even earlier Graz cosmologist



“When the state is threatened by shipwreck, we can do nothing more noble than to lower the anchor of our peaceful studies in the ground of eternity.”
- *J. Kepler*

1600-1630: Graz → Prague → Linz → Sagan → Ratisbon



“There’s a lot of history in the forum”

Chicago at night

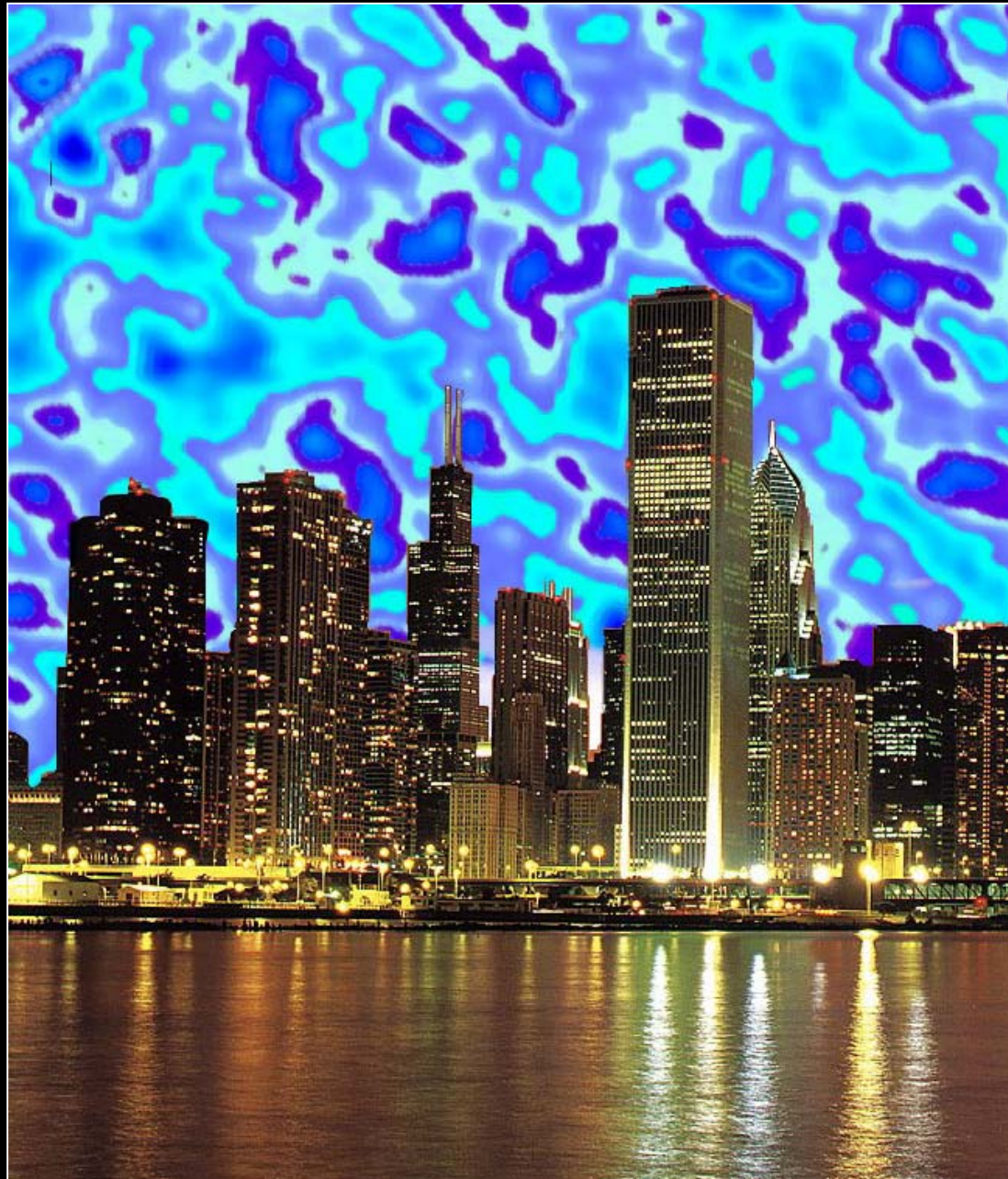


The microwave sky

$$T = 2.728^\circ \text{ K}$$



hot and cold spots
differ by
30 parts
per million

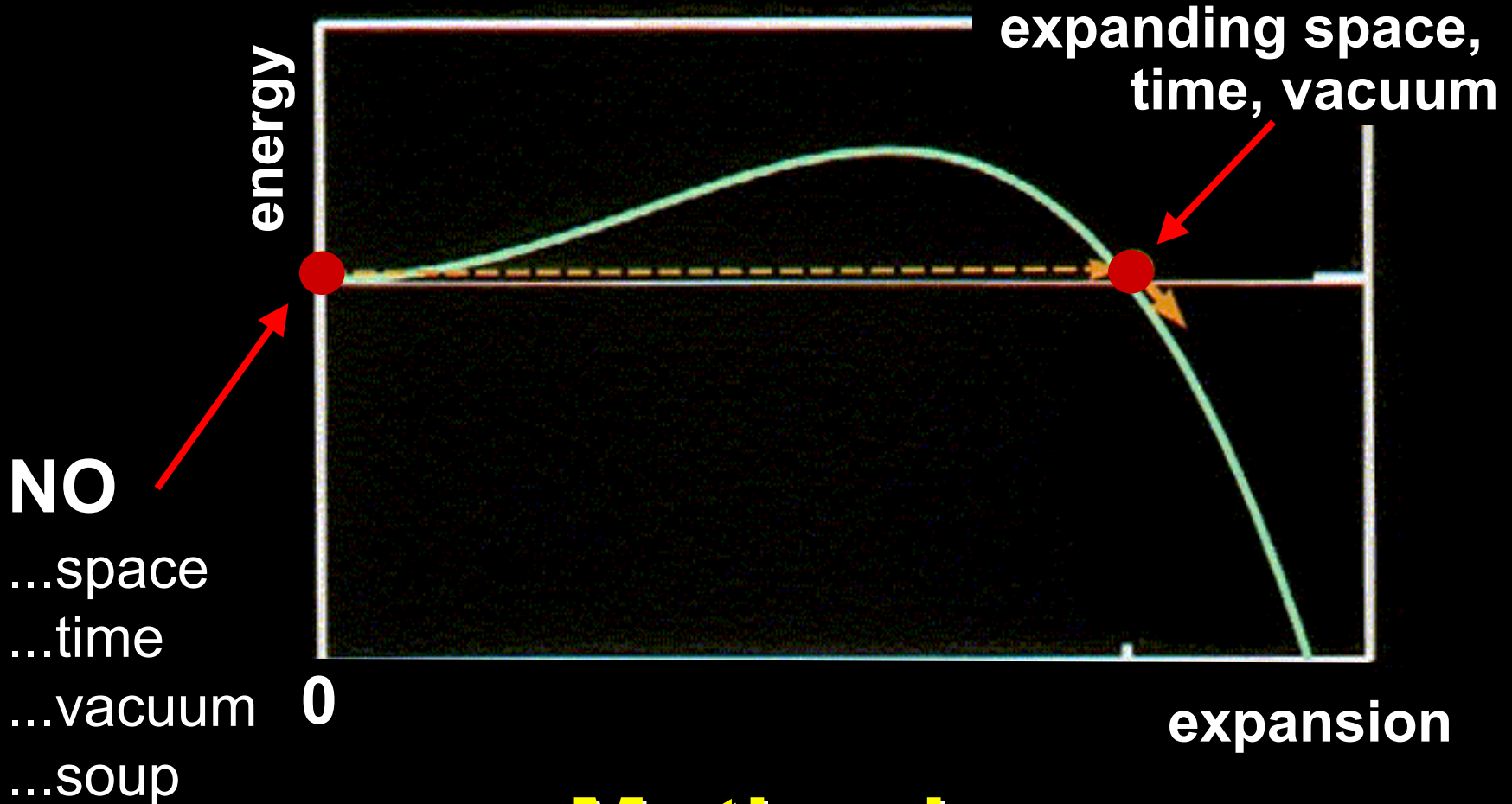


Before nothing?

NOTHING HAD A BEGINNING:

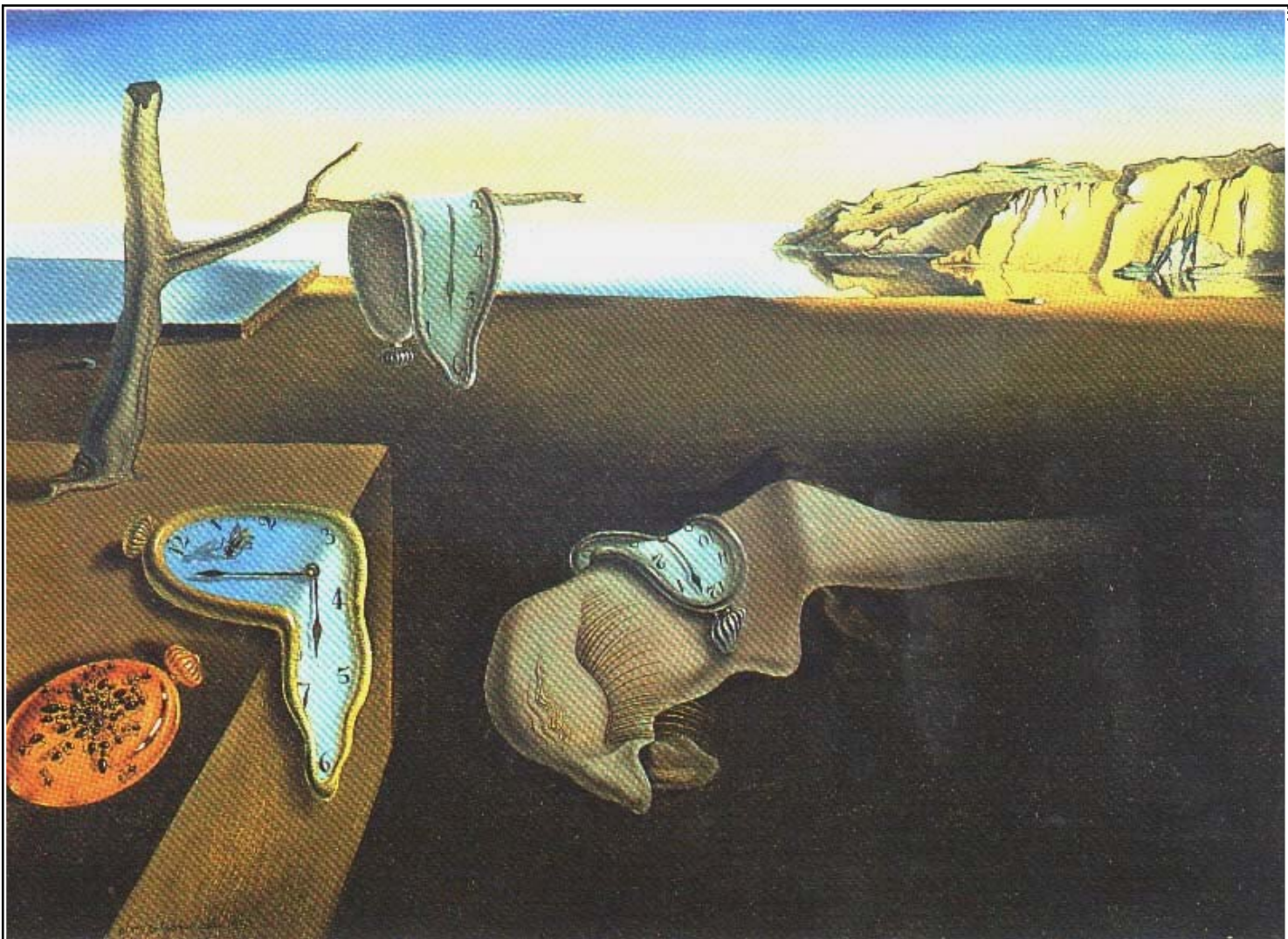
- quantum creation of space, time, vacuum *from less than nothing.*
- nothing is unstable -- emergence of the universe is *inevitable.*

Quantum tunneling



**Motion in
“IMAGINARY TIME”**

Imaginary time



Before nothing?

NOTHING HAD A BEGINNING:

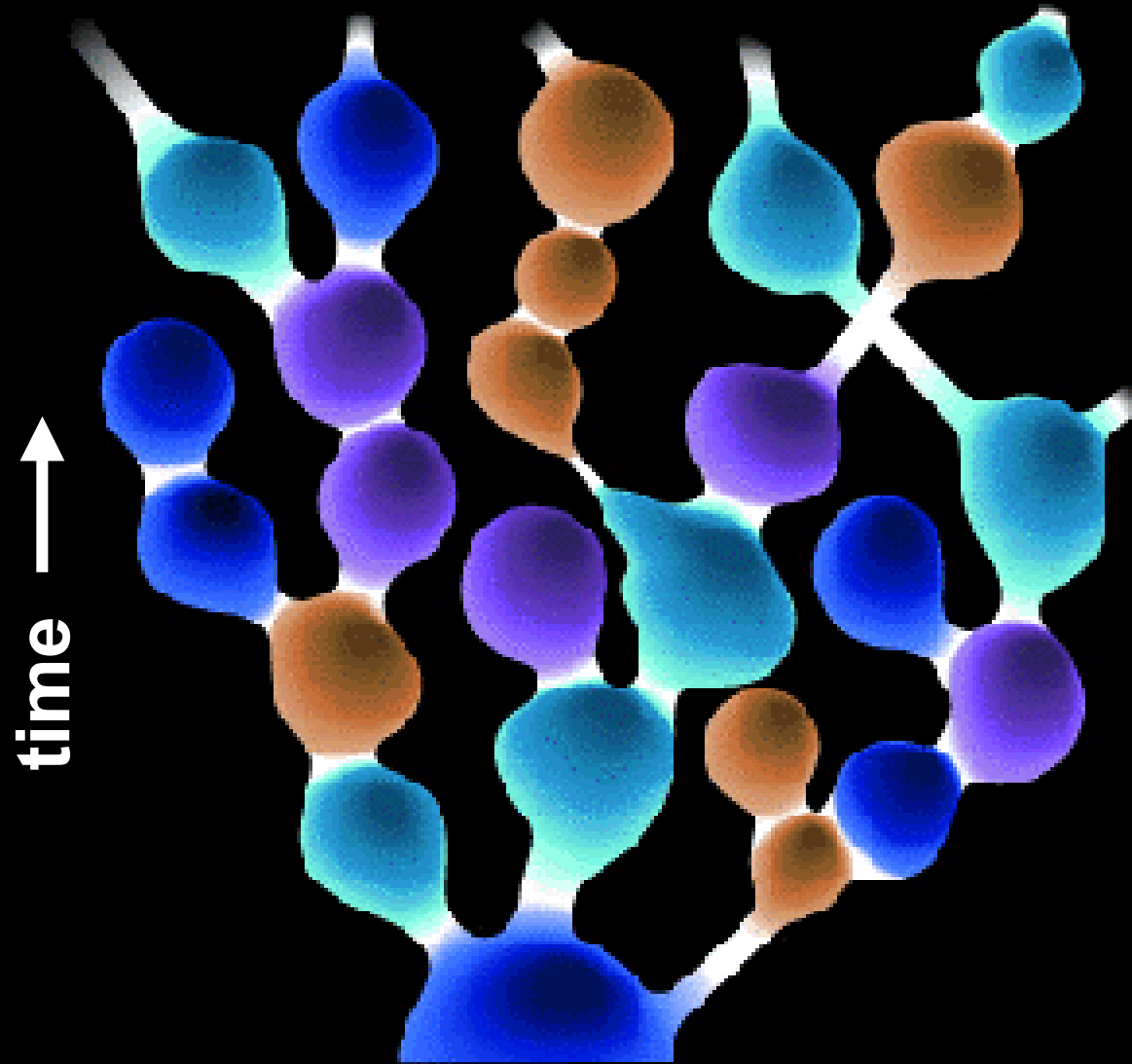
- quantum creation of space, time, vacuum *from less than nothing.*
- nothing is unstable -- emergence of the universe is *inevitable.*

NOTHING IS ETERNAL:

- universe is *still inflating.*
- on largest scales, universe is unchanging -- *no beginning and no end.*

Quantum fluctuations lead to many different bubbles

Eternally self-reproducing universe



Universe has no beginning....no end

Each bubble grows to cosmological size

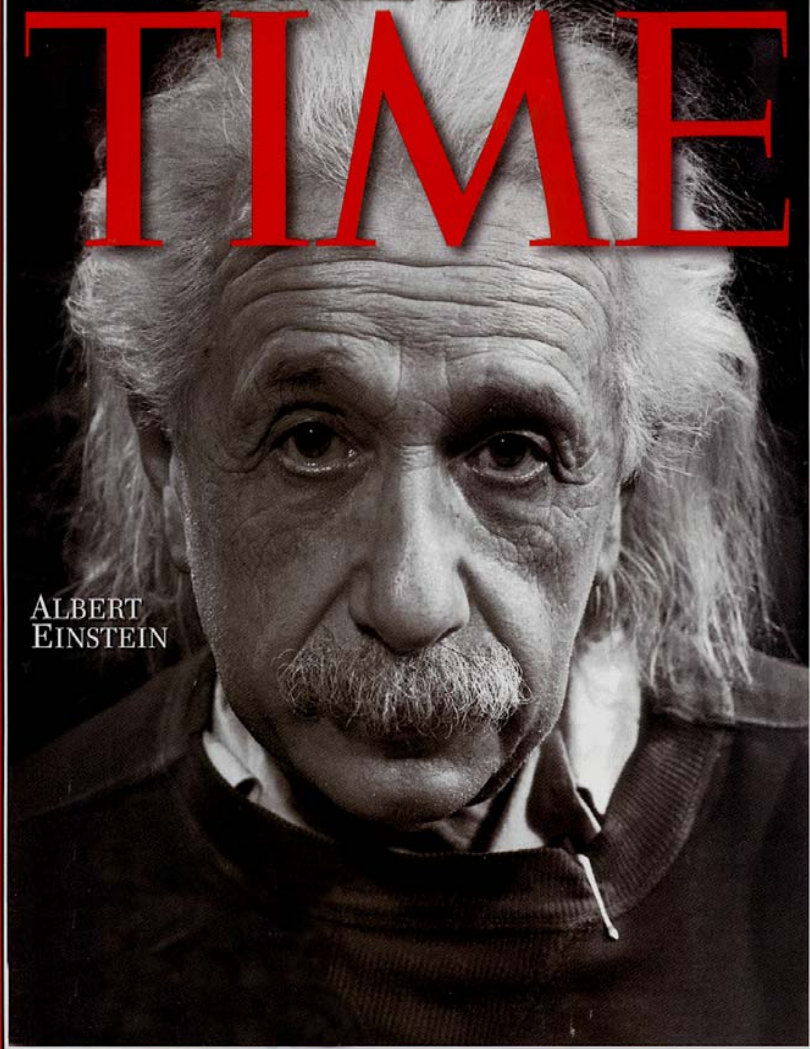
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Il quanto e il cosmo



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